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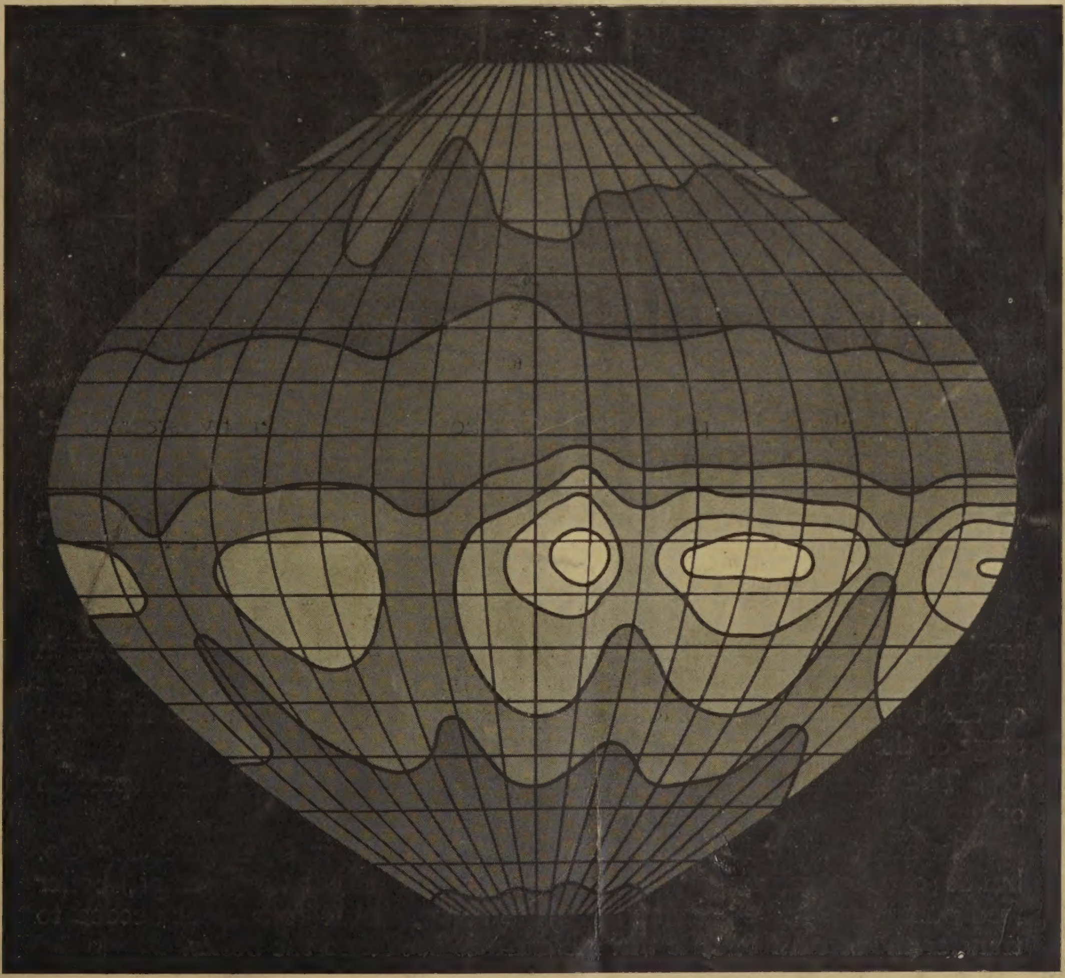


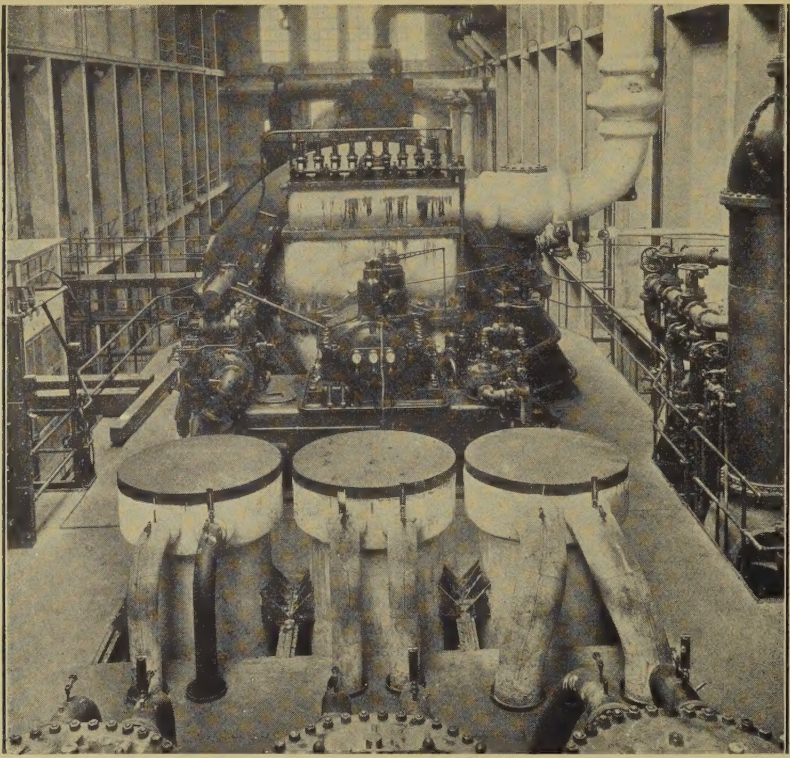
A STUDY IN LIGHT AND SHADE

An artist's rendering of the zone variations in light distribution on an imaginary sphere enclosing a large ornamental lantern type of lighting unit, as reproduced from a recently developed method of plotting distribution diagrams

(*See Fig. 8, p. 274*)

In This Issue:

- *High Angle Radio*
- *Railway Economies*
- *A Texas Electrification*
- *Crystal Structure Analysis*
- *Isocandles*
- *Electrified Farming*
- *Magnetic-time Controls*
- *Adjustable Speed A-C. Motor*
- *Charles A. Coffin Foundation Awards*



Wheeler-Wainwright Bleeder Heaters at Westport Station, Consolidated Gas, Electric Light and Power Co., Baltimore, Md.

MODERN power plants heat the boiler feed water by steam bled from the main unit.

WHEELER-WAINWRIGHT BLEEDER TYPE FEED WATER HEATERS AND GLAND STEAM CONDENSERS

are built to withstand the conditions of pressure and temperature met with in this service. Wainwright heaters may be installed on the discharge side of the boiler feed pumps and may be supplied with steam bled from any stage of the turbine, whether saturated or superheated.

The tubes of Wainwright heaters are easily accessible for inspection or repair.

In addition to heaters, the Wheeler Condenser & Engineering Co. builds condensers, air pumps, hotwell pumps, circulating pumps, boiler feed pumps and make-up evaporators, in short, all the equipment needed to transfer the steam from the turbine exhaust back into the boiler.

WHEELER CONDENSER & ENGINEERING CO.

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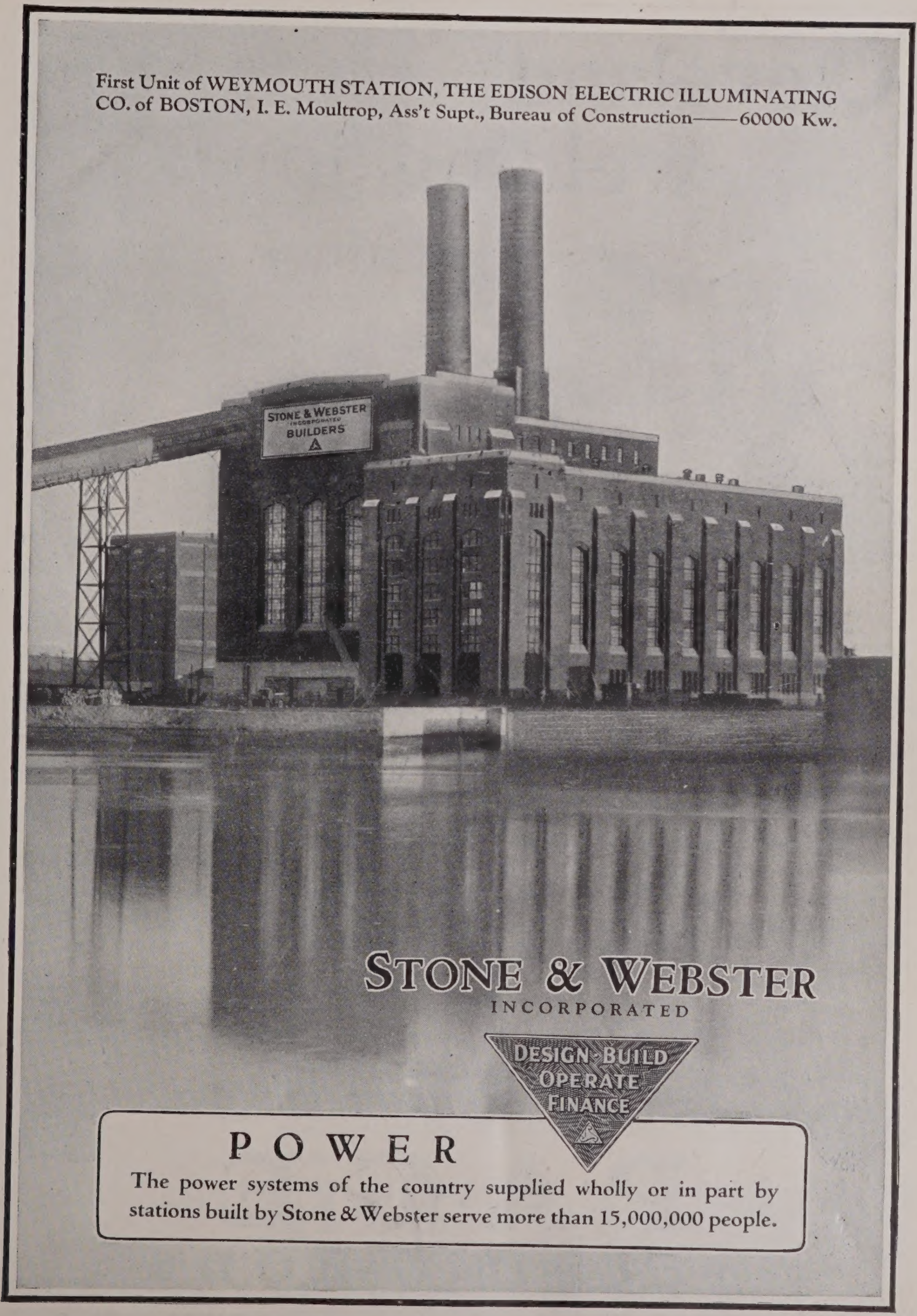


First Unit of WEYMOUTH STATION, THE EDISON ELECTRIC ILLUMINATING CO. of BOSTON, I. E. Moultrop, Ass't Supt., Bureau of Construction——60000 Kw.

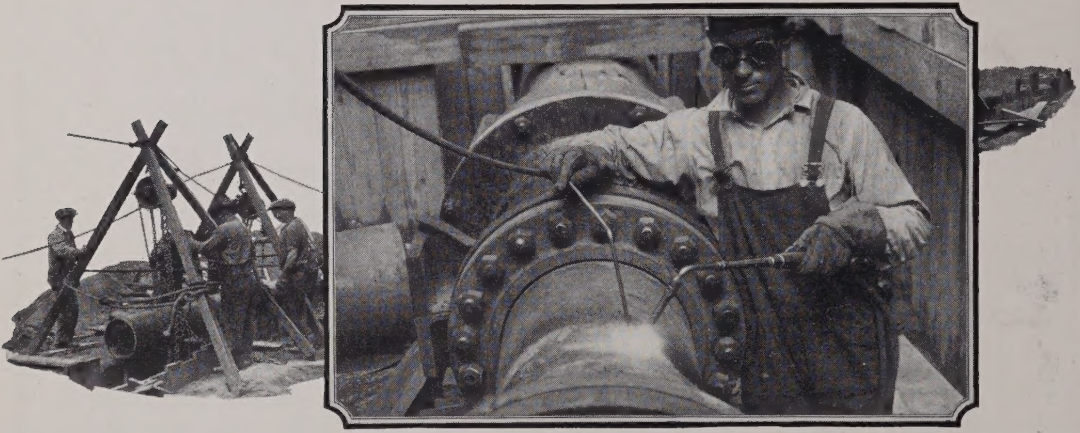
STONE & WEBSTER
INCORPORATED

DESIGN-BUILD
OPERATE
FINANCE

POWER

The power systems of the country supplied wholly or in part by stations built by Stone & Webster serve more than 15,000,000 people.

Cleveland's *remarkable* welding job



PAGE-ARMCO WELDING RODS, used to weld 6000 ft. of 16″ steel pipe ½″ thick, pressure steam line of the Cleveland Electric Illuminating Company, Cleveland

6000 *feet of* 16-*inch high pressure steam line*

EACH welded joint has to stand 500 lbs. test. Five pounds of added metal is applied to each joint.

The welding men naturally chose Page-Armco, the most uniform, easiest flowing, gas-free rods on the market. It saved time—gave them a better job.

Rods are a small part of welding cost. Can you *ever* afford to take chances—use any but the best? Try PAGE-ARMCO, time the job, and inspect it and test it.

PAGE also makes high carbon rods—rods of all types for gas, electric and automatic welding. Write for illustrated folder telling how better rods cut welding cost. No obligation. A card will do.

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ARMCO Ingot Iron

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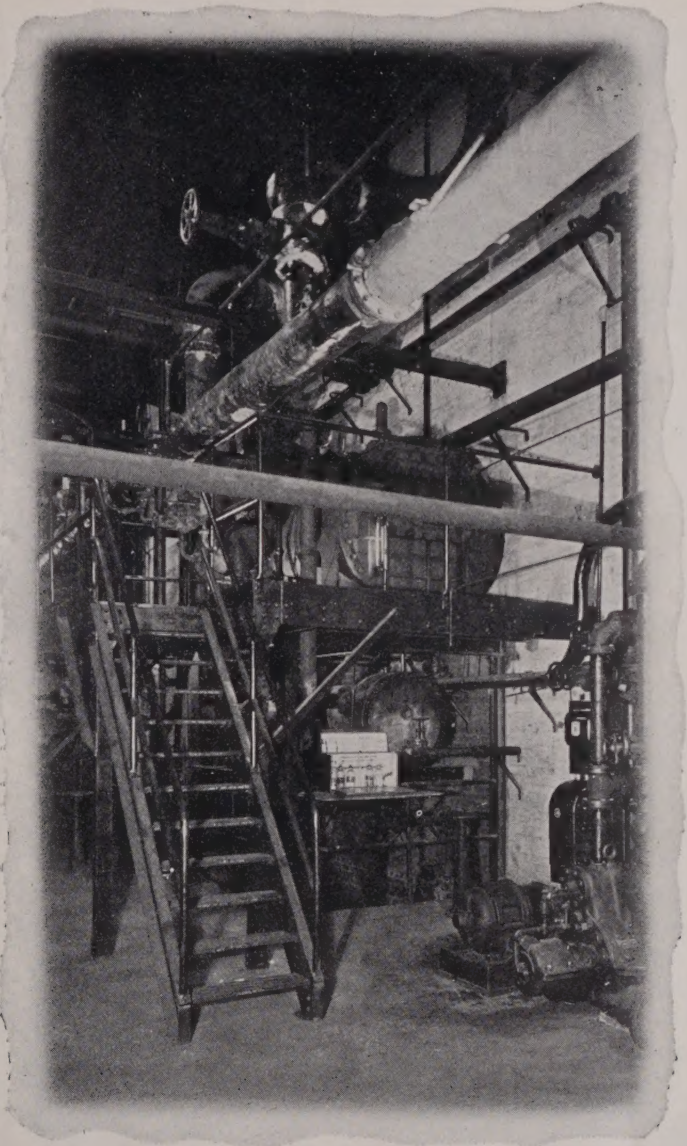
WELDING RODS



Elliott Deaerator of 75,000 lbs. per hour capacity in the Detroit Avenue Station of the Toledo Edison Company, Toledo, Ohio.

Protecting 100 miles of piping against corrosion

THE Detroit Avenue Station of the Toledo Edison Company is the largest central hot water heating plant in the world. It serves approximately 2000 homes over an area of 3½ square miles. The piping system includes over 100 miles of underground pipe. An extensive field where corrosion could cause infinite damage!

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Elliott Deaerators offer a complete solution to the corrosion problem in boilers, economizers and piping for any station experiencing corrosion troubles.

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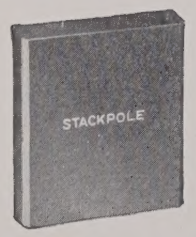
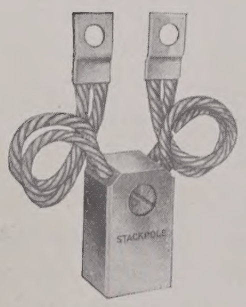
Research did it





And research is continuing to do it—producing a carbon brush of a pure, even and uniform composition.

The Stackpole Carbon Brush is the result of analyses and tests carried on by an efficient corps of engineers and chemists through a period of a long number of years.

Although the Stackpole Brush is generally conceded to be of the first rank, it is not the ultimate in carbon brush manufacture.

The electrical industry is continually developing; and to meet this growth our laboratories are incessantly experimenting and remedying difficulties that are confronting our customers.

For whatever requirement you have in mind—or will have—a Stackpole Carbon Brush will meet that need in a most gratifying fashion.

Write for your copy of Stackpole Catalog No. 8.

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Stackpole *carbon brushes*

New Departure Ball Bearings

BALL BEARINGS—

the Latest Achievement in Motor Economy

NEW DEPARTURES are as long lived as the motors themselves. They can be housed to permanently prevent the leakage of lubricant or entrance of abrasive foreign material.

From these two basic superiorities follow many additional advantages:

The motor has a longer life because the rotor cannot rub on the stator.

The motor shaft and rotor are always in correct position, maintaining highest efficiency and power-factor.

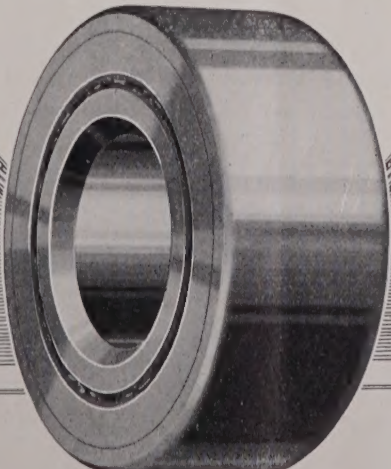
The lubricant stays in the bearing closure, keeping insulation free of oil, giving exceptionally long life to the windings.

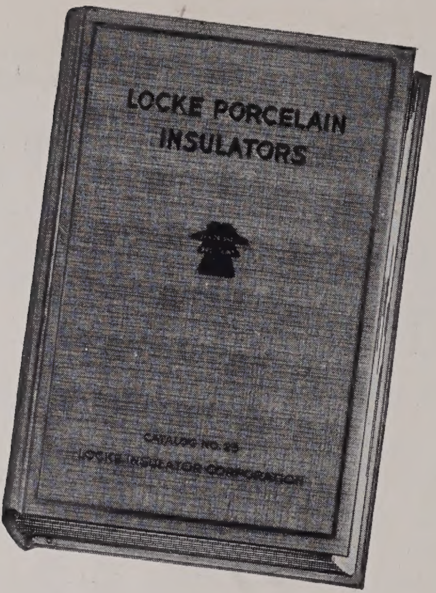
The motor has a lower maintenance cost. Important economies are effected in upkeep expense because lubricant need be supplied only at infrequent intervals. The motor seldom needs cleaning. Rewinding expenses are practically eliminated.

The surface of the motor is free from oil which would damage material in process.

New Departure Ball Bearings permit a very compact motor design because of minimum space occupied along the shaft,

THE NEW DEPARTURE MANUFACTURING COMPANY
Detroit *Bristol, Conn.* Chicago





NEW catalog No. 25

THIS new catalog surpasses all previous attempts to lay before you a comprehensive listing of Locke products.

It is more than a catalog. It is a valuable reference work on the subject of porcelain insulators. It gives up-to-date specifications and tests, together with mechanical and electrical data, on all Locke standard insulators, as well as complete information on hardware, protective devices and other equipment for every insulation requirement.

A summation of the contents of this catalog is concisely given in the foreword:—

> "Locke porcelain was first marketed in 1894. For thirty years Locke engineers, with every facility for research, have striven to improve both material and design, and to determine, from study of operating conditions, the particular design best fitted to given loads and given climatic conditions.
>
> The results of these thirty years' experience are embodied in the following pages."

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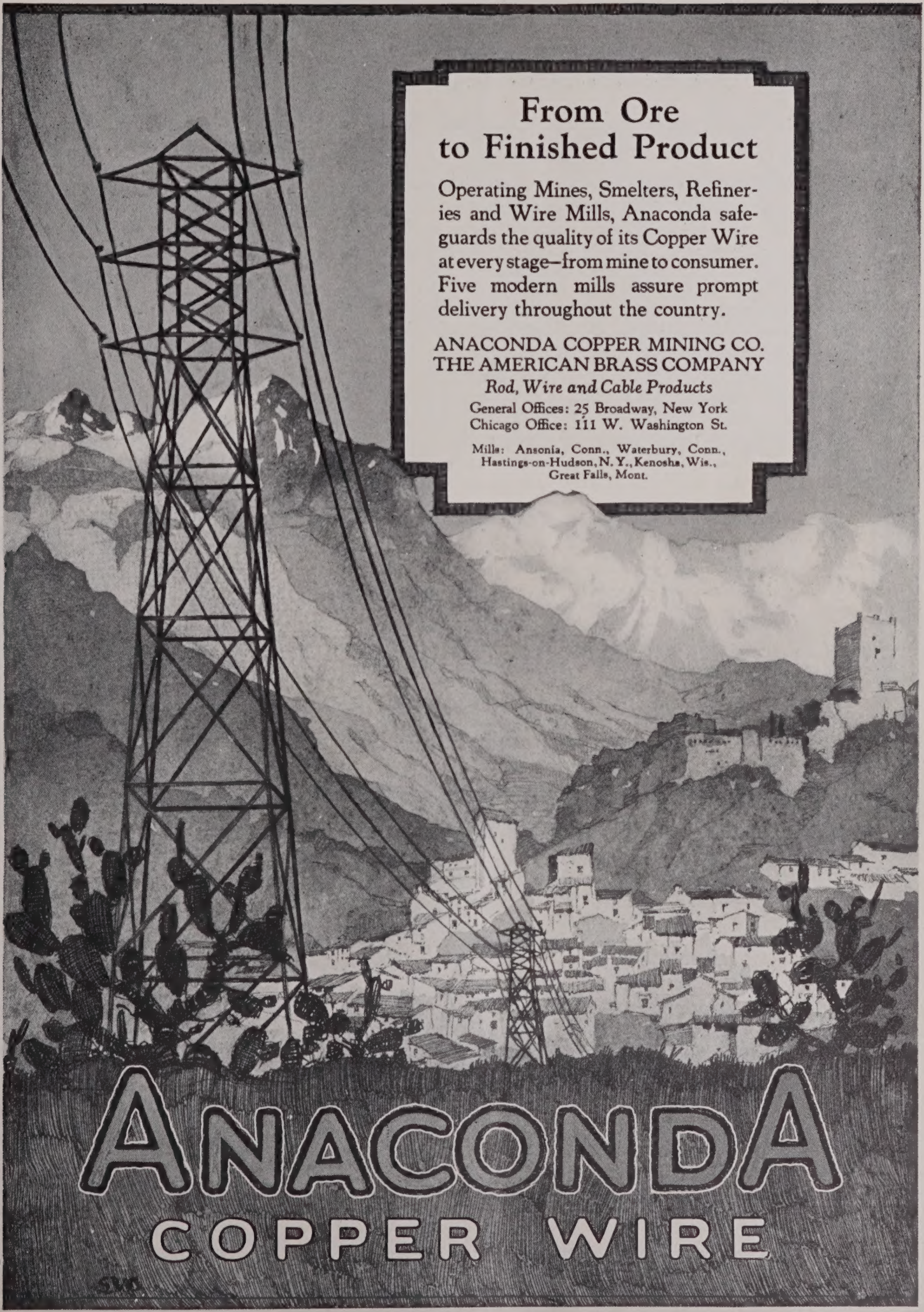

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The Patented 5-step Automatic Clearance Control which regulates the air output of Ingersoll-Rand Compressors assures this economy. With this method of regulation, a constant-speed motor-driven compressor delivers only the air required to meet the existing demand.

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The Operation of the Clearance Control is Automatic

With the Clearance Control it is not necessary to anticipate changes in the air required. Its action is entirely automatic, being governed by changes in the air receiver pressure.

Bulletin 3226 describes Ingersoll-Rand direct-connected, motor-driven compressors. It tells all about the Clearance Control. Send for your copy now.

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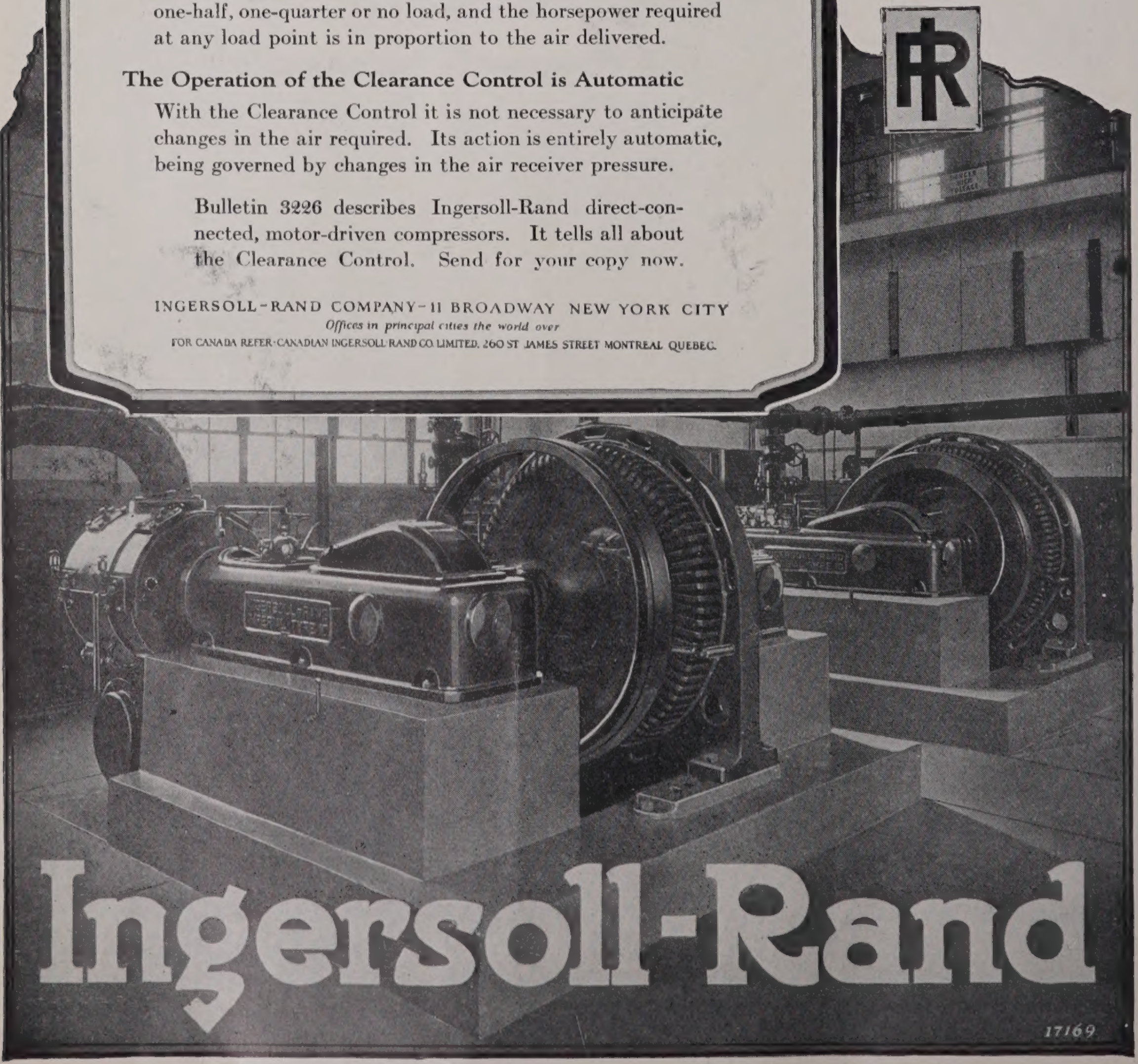

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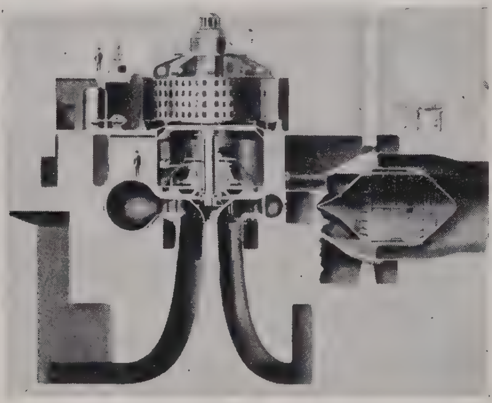

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St. Croix Paper Co.	1	4550	48
Kentucky Hyro Electric Co. (Dix River Development)	3	9850	220
Roanoke Rapids Power & Light Co.	1	3200	30
Niagara, Lockport & Ontario Power Co. (Lighthouse Hill Project)	2	5250	62
Northern New York Utilities Co. (Soft Maple Development)	2	10500	121.5
Great Northern Paper Co. (Anson Plant)	1	1500	20
Illinois Northern Utilities Co. (Dixon Plant)	4	800	8
Middle West Utilities Co.	1	800	8
Phoenix Utility Company (Wallenpaupack Creek)	2	28500	330
Merced Irrigation District (Exchequer Power Plant)	2	24500	300
Gifu Electric Power Company (Aso Station)	3	13000	169
Phoenix Utility Company (Cutler Development)	2	21500	124
Great Northern Paper Company (Dolby Mill)	1	2400	49
	3	1800	49

MANUFACTURED IN MONTREAL

	No. of Units	Horse Power Per Unit	Head In Feet
Spruce Falls Company, Limited	1	2500	25
East Kootenay Power Company	2	7500	190
Northern Ontario Light & Power Co. (Matabitchouan Plant)	4	3300	305
Montreal Light, Heat & Power Cons. (Cedars Plant)	4	11300	30
Montreal Light, Heat & Power Cons. (Cedars Plant)	2	1500	30
Price Bros. & Company, Limited	1	11000	72
Howard Smith Paper Mills, Limited	2	350	8
Hydro-Electric Power Commission of Ontario (Queenston Chippewa Development)	1	58000	294
St. Maurice Power Company	4	30000	60
Rolland Paper Co., Ltd.	1	750	20
Northern Canada Power Co.	2	10000	70
Hollinger Gold Mines, Ltd.	2	12000	60
Southern Canada Power Co.	6	5600	50
Northern Aluminum Co.	6	3450	136
Hydro-Electric Power Commission of Ontario (Queenston, Chippewa Development)	1	58000	294
Southern Canada Power Co., Ltd. (Drummondville Development)	2	6000	50
Canadian Pacific Railway Company (Lake Louise Plant)	1	440	108

1,169,950 Horse Power to be Delivered by I. P. Morris Turbines Contracted for Since January 1, 1922

I. P. Morris Hydraulic Turbines Installed and under Contract have a total Capacity of 3,844,180 Horse Power

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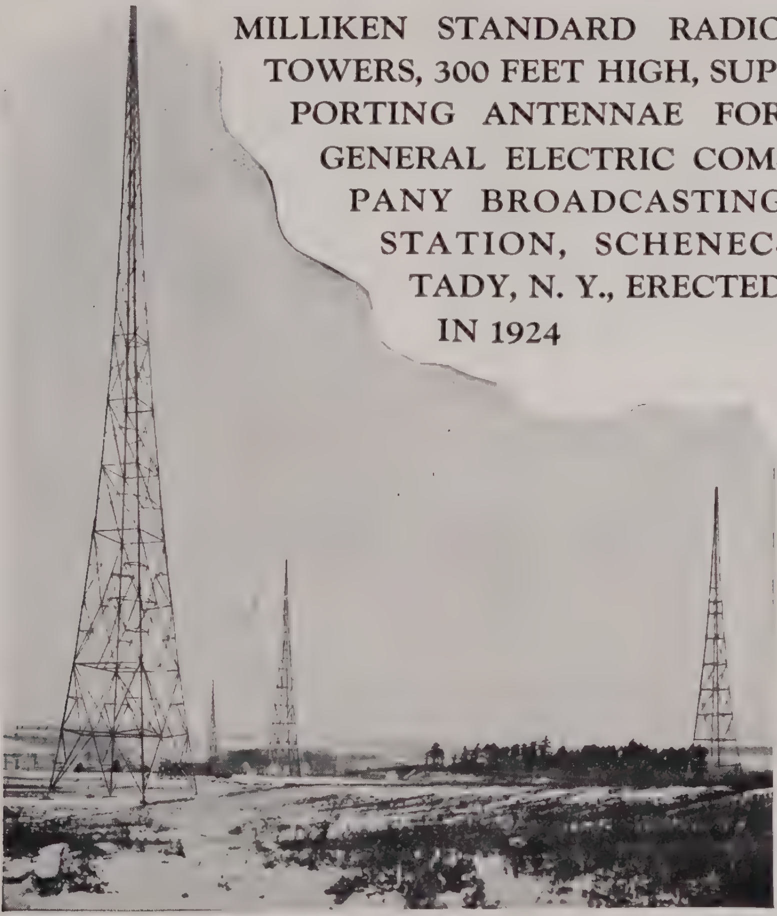

MILLIKEN STANDARD RADIO TOWERS, 300 FEET HIGH, SUPPORTING ANTENNAE FOR GENERAL ELECTRIC COMPANY BROADCASTING STATION, SCHENECTADY, N. Y., ERECTED IN 1924

MILLIKEN Standard Radio Towers, 300 feet high, are being used by the General Electric Company at its new experimental broadcasting station, Schenectady. These towers were selected by the leading broadcasting station in the world for stability, reliability, long life and economy, to secure the best results in long distance service.

The General Electric Company leads in all electrical development and specialized broadcasting equipment. This station represents the last word in experimental broadcasting.

MILLIKEN Standard Radio Towers are hot galvanized throughout. They are carried in stock for immediate shipment and are furnished in heights ranging from 66 feet to 300 feet.

Milliken towers are used also at such important broadcasting stations as—

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WEAF—American Telephone and Telegraph Co., New York
WSAI —United States Playing Card Co., Cincinnati
WEEI —Edison Electric Illuminating Co., Boston
WBZ —Westinghouse Electric & Mfg. Co., Springfield, Mass.
WHAZ —Rensselaer Polytechnic Institute, Troy, N. Y.
WMAF—Round Hills Radio Corporation, Dartmouth, Mass.
WCX —Detroit Edison Co., Detroit
WGBS —Gimbel Brothers, New York
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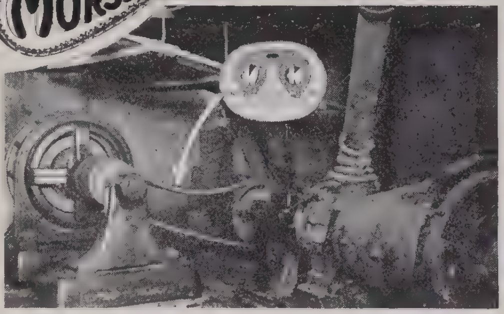

150-H.P. Morse Silent Chain driving Jordan engine.

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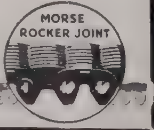

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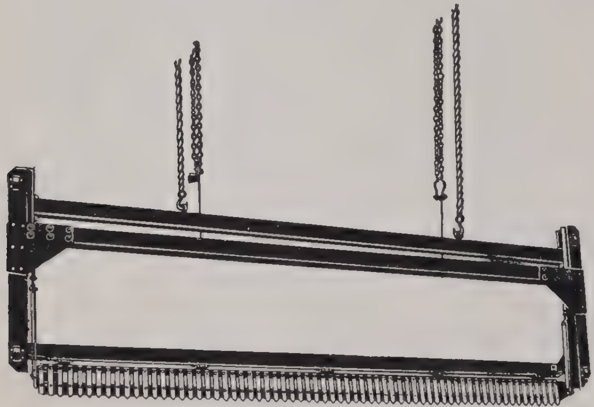
NEWPORT NEWS RACK RAKE

WILL SOLVE YOUR TRASH PROBLEMS



One customer recently stated "We now have no trash problems."

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Builders of large hydraulic turbines and accessories, including butterfly valves and headgates, with operating gear; electrically welded trash racks, penstocks, surge tanks, etc.

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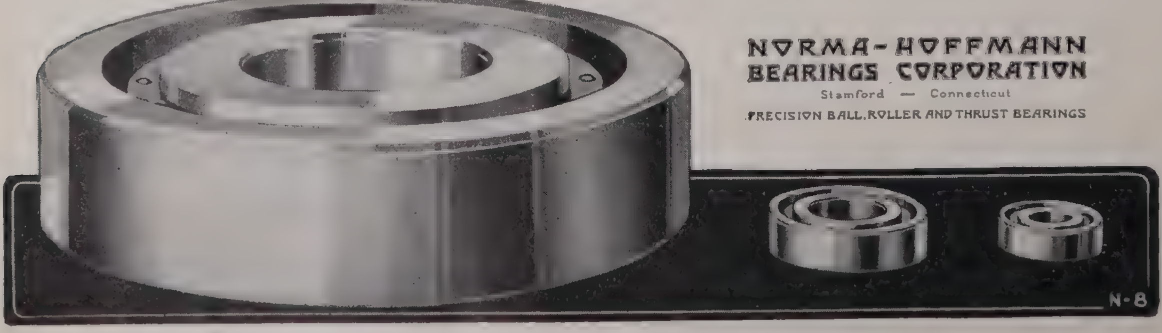

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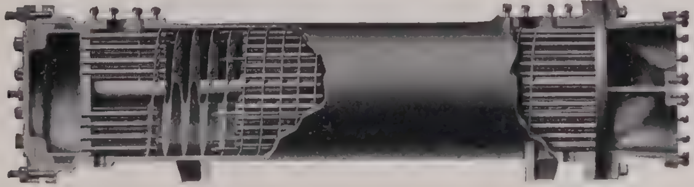

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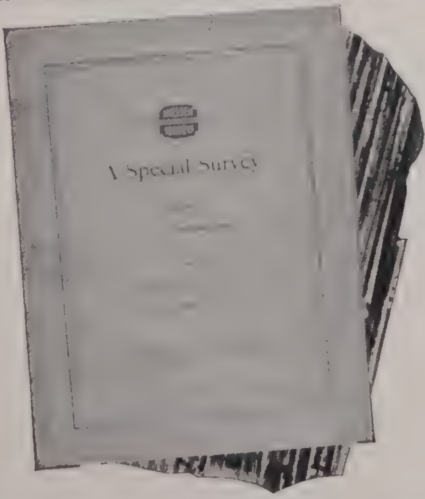
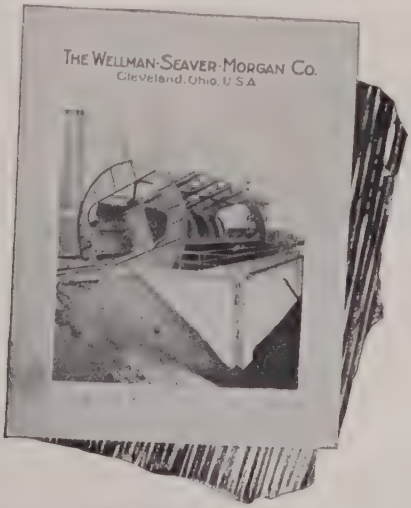


A Special Survey



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GENERAL ELECTRIC REVIEW

A MONTHLY MAGAZINE FOR ENGINEERS

Manager, M. P. RICE Editor, JOHN R. HEWETT Associate Editor, E. C. SANDERS

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CONTENTS

PAGE

Frontispiece: C., M. & St. P., 3000-volt, Direct-current, Gearless Locomotive . . . 212

Editorial: Electrification Pays 213

Farm Electrification in New York State 214
By Owen D. Young

Electrification Economies on the Chicago, Milwaukee & St. Paul Railway 218
By W. D. Bearce

Comparative Cost of Steam and Electric Operation 229
By A. H. Armstrong

Joint Operation of Steam and Electric Trains Over the Dallas-Denton Division, Texas . 237
By B. F. Cooke

The Mill-type Magnetic-time Control System 243
By J. D. Wright

The Adjustable-speed Alternating-current Motor with Shunt Characteristics 248
By H. C. Uhl

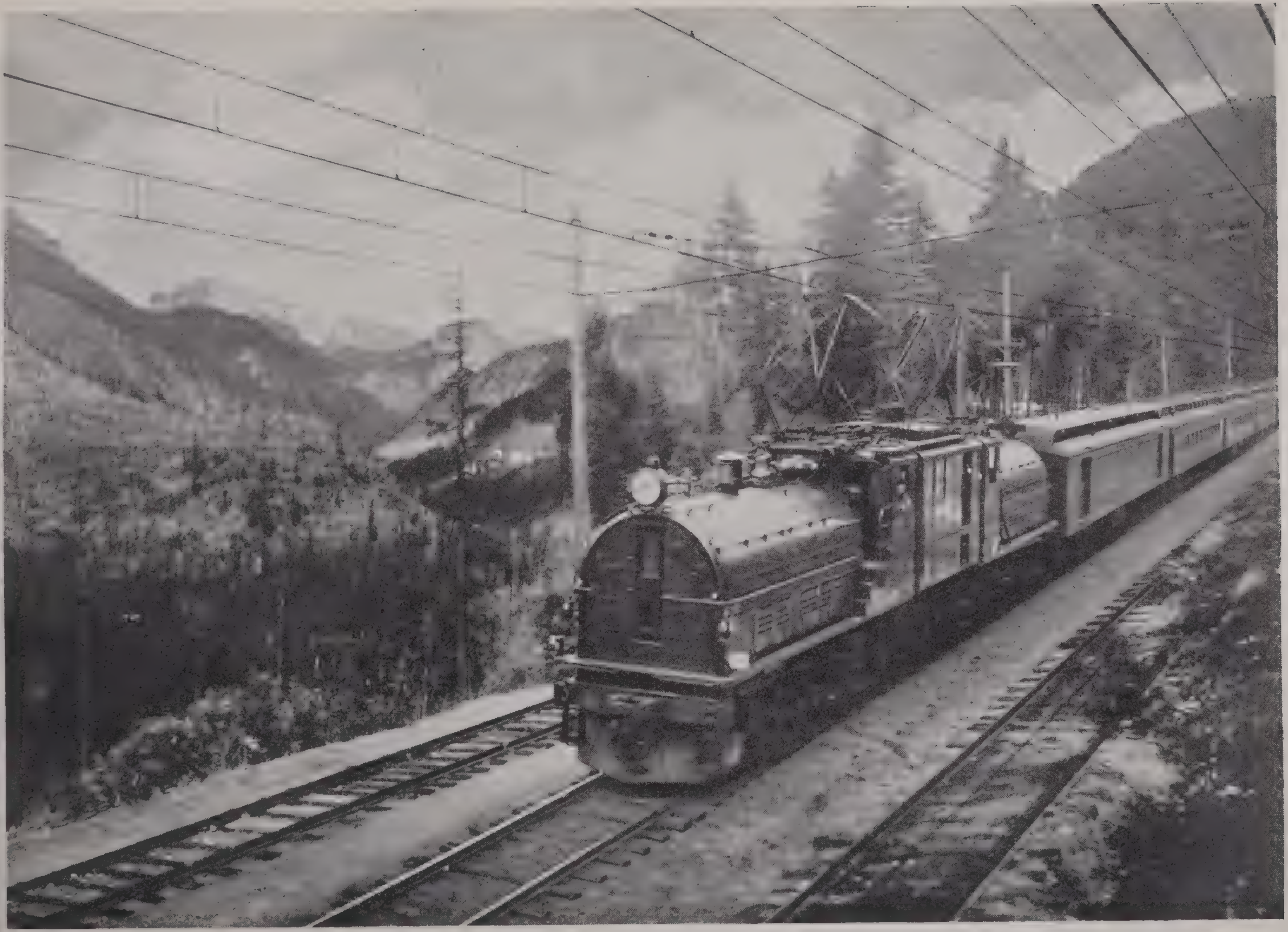
Study of Crystal Structure and Its Applications. Part IV 258
By W. P. Davey

New Fields for Radio Signalling 266
By E. F. W. Alexanderson

Isocandles and the Asymmetric Lighting Unit 271
By Frank Benford

Charles A. Coffin Foundation Awards to General Electric Employees for 1924 . . . 277

Library Section 280



UPHILL, DOWNHILL, OR ON THE LEVEL, IT'S ALL THE SAME TO THE ELECTRIC LOCOMOTIVE

A 3000-volt, Direct-current, Gearless, Passenger Locomotive Hauling Train Through the Scenic Cascade Region on the Chicago, Milwaukee & St. Paul Railway's Lines

(See pp. 218 and 229)

GENERAL ELECTRIC REVIEW

ELECTRIFICATION PAYS

In contrast to the steam locomotive, the electric locomotive is capable of hauling any weight of train at any speed permitted by strength of draft gear and alignment of track. There are no inherent limitations in the application of motors to driving wheels which handicap the construction of electric locomotives. Power units far in excess of the needs of train operation as now conducted could therefore be built without departure from present standards of electric construction. Future transportation requirements with regard to both train weights and speed on any gradient will not be restricted by any inherent limitations of electric motive power.

The economic side of steam road electrification is now presented in detail in the complete report of President Byram covering an analysis of steam and electric operation on 646 miles of the St. Paul main-line track. An abstract of this report and comments on the electrification appear in the articles on pages 218 and 229 of this issue. The publication of these data is especially timely as it clears up any doubt that may exist as to the part played by electrification in the financial difficulties through which the St. Paul road is now passing. Electrification, as shown, has reduced operating costs by more than $19,000,000 in 8½ years as compared with calculated steam costs under the same conditions. Even after deducting interest and depreciation charges on the $15,000,000 addition to capital account, there is a net saving of over $12,000,000 to be credited to electric operation. This showing is all the more remarkable as the period of operation covers 8½ years of the Montana Division and less than 5 years of the Coast Division. Furthermore, the volume of tonnage during this period has been small measured by the standard of many other railroads and much below expectation, except during the year 1919. The economic benefits resulting from electrification would have been much greater on more congested tracks, and the report holds a most attractive promise of gratifying return upon the investment for electrification of other roads enjoying a fair volume of tonnage per mile of track.

To the many foreign commissions and to various individual consulting engineers in this country and abroad, the results published in Mr. Byram's report will be most illuminating.

The analysis of operating costs on the Chicago, Milwaukee and St. Paul electrification is of particular interest, since this was the first 3000-volt direct-current installation. The performance of 3000-volt equipment has also been highly satisfactory in subsequent installations, notably on the Paulista Railway in Brazil. To American railroad men these operating costs are of course much more convincing than those obtained on foreign roads where labor and material conditions are vastly different.

Although the electric locomotive demonstrated its ability to handle heavy main-line traffic more than 20 years ago, conditions have been such that only a few of the many railroad companies have published comprehensive operating data. It is to be hoped that with the gradual increase in the extent and the number of electrified railroads more data of this kind will become available upon which indisputable recommendations can be based.

Farm Electrification in New York State

By Owen D. Young

Chairman of the Board of Directors, General Electric Company

In view of the awakening of public interest in rural electrification, we are reproducing below an abstract of Mr. Young's speech of April 6th before a meeting of representatives of farm, university, and electric public utility organizations held under the auspices of the Empire State Gas and Electric Association at Albany, N. Y. In reading it, cognizance should be taken of the fact that many of the statements made in reference to New York State apply equally well elsewhere.—Editor.

The electrification of the farm requires the co-operative effort of the farmer, the electric light and power company, and perhaps most of all, the electrical manufacturer. The problem is difficult, but it must be solved. Farms must be made attractive as a place to live, and profitable as a business. Their produce must be made as abundant and cheap as modern devices and inventive genius can make them, in order to guarantee our food supply. As a social problem, life on the farm, and particularly in the farm houses, must be relieved of its exhausting drudgery through the application of electric power, just as we have relieved its desolating lonesomeness by the telephone, the automobile, the motion picture, and most of all, by the radio.

The farm can be and is being made the best of all places in the world to live. The business of farming must be made to yield profits commensurate with other business. I welcome that Monday morning when the electrically-driven milking machine shall have milked the cows; the electrically-driven separator shall have produced the cream; the electrically-driven churn shall have made the butter. At the same time in the house, the electrically-driven washing machine shall be automatically doing its work while breakfast goes on and we shall have sunny, bright, and happy Mondays in place of the old blue ones. And they were blue, and rightly blue in the old days with the milk coming into the house from the barn; with the skimming to be done, and the pans and buckets to be washed; with the churn waiting attention; with the wash-boiler on the stove while the wash-tub and its back-breaking device, the wash-board, stood by; with the kitchen full of steam; the breakfast cooking in progress, and one pale, tired, and discouraged woman in the midst of this confusion. Hungry men were at the door anxious to get at the day's work. Blue were those Mondays indeed.

"How to Electrify the Farm?" can be solved only by answering four other questions:

1. What can the farmer do?
2. What can the power company do?
3. What can the manufacturer do?
4. What can the State do?

What Can the Farmer Do?

First, let us see what the farmer can do. Above all, he must be interested in his business. He must be open-minded, and hungry to find new methods by which he may make his undertaking both more pleasant and more profitable. Pride in the advancement of his business, and the initiative to advance, are essential. Leadership must come from the men who own and live on their farms and take pride in their business. The farmers should insist upon the study of electrification by their agricultural schools and colleges, by their farm organizations, and require a constant and unending publicity of the results of such studies through their farm journals. They should welcome study by the power companies and the manufacturing companies, and should co-operate with them to work out practical plans to get effective results. In each community, they should endeavor to develop a universal sentiment in favor of a power supply and general agreement to take the service in order that rights-of-way may be economically obtained, and the cost of service distributed over the largest possible number of customers. Both the automobile and radio are later developments than electric light and power. They have had wide sale among farmers. It is probably explained by the fact that these may be individually bought, whereas electric service requires co-operative group action. The farmer is too much of an individualist to be a good co-operator. He must learn to co-operate if he is to get electric service. To sum up, I ask the farmer to show the same initiative in the development of his business that the manufacturer does. I ask him to be open-minded as to new methods and to show a readiness to abandon the old. I ask him to learn to co-operate with his neighbors for their mutual benefit, as well as to act individually on his own account. I ask him to exert both economic effort and his political influence to create such favorable conditions for the supply of electric service as to insure proper results.

The one point I want to make to the farmer is that the manufacturing companies may produce devices, the electric power companies may bring electricity to his door, but the question remains with the farmer whether he will put it to work. It is he, in the last analysis, who must say whether or not electricity is to be used in agriculture.

What Can the Power Company Do?

The power company can show such interest in the study of the needs of the farmer as a potential customer as it has heretofore done so effectively with reference to industrial and commercial customers. When the great hammers of a steel works needed power, the electric power man was there with his motor and his wire. When the coal mines were using mules to haul the coal to the surface, he was there with his electric locomotive, his elevator, and his wire, and he put the poor mule out of business. When the textile and other similar mills were full of belts and shafting, impairing light, creating noise, and endangering life, he was there to relieve the situation with his individual motor and his wire. When the bake shop needed ovens, he was there with his heating devices and his wire. When the stores needed light, he was there with his highly developed specialized lamps and his wire; but when the cows were to be milked, when milk was to be separated, when the cream was to be churned, when the curd was to be cut, when silos were to be filled, when grinding machines were to be run, unfortunately the electric power man was not there with his motor and his wire. He has been largely interested in serving these other larger consumers in more concentrated areas. I am not criticizing the power companies for what they have failed to do. I am commending their spirit of today. Their achievement in this country as compared with the development in any other is one of the outstanding testimonials to the energy and ability of the men who have directed this great industry. All I wish to say to them is that, having made such progress in these other fields, and having from necessity so long neglected the agricultural need, the time has come when they should now give special attention and study to agricultural problems and to ways and means of furnishing agricultural service. They should create agricultural departments with men who not only know the electrical business, but who know the farming business. It will not do for the electric power companies to send men to the farms who do not know on which side of the stanchions to install a milking machine. One reason why the farmer has not been open-minded is because the people who have been trying to sell him electric service have really known nothing about his needs.

Just as the electric light and power companies now have Industrial Departments, they should, in the future, have Agricultural Departments. These departments should be in the hands of men familiar not only with electricity, but with farming. They should be in close touch with the agricultural schools and colleges. They should be working through co-operative committees, such as the Joint National Committee on the Relation of Electricity to Agriculture and the New York Rural Lines Conference Committee. This New York Committee is composed of representatives from the State College of Agriculture at Cornell, the New York Farm Bureau, the State Grange, the Home Bureau, and the Empire State Gas and Electric Association. In my judgment, the power companies and the manufacturing companies should aid the work of this Committee, not only with skilled men, but by providing it with such funds as may be necessary to enable it to do its job.

Now, again, let me say a word about what I conceive to be the increasing obligation of power companies to supply service to the smaller communities and the agricultural districts. Twenty-five years ago the light and power companies did a local business in each municipality. A generating station suited to the size of the community in which the franchise was granted, and a distributing system adequate to cover its needs was a power company. Within that community, it was their privilege and their obligation to supply service to its citizens. Each individual service might not be wholly profitable, but if the earnings from the community as a whole showed a fair return on the capital invested there, the power company was satisfied. Today, a change has occurred in that business. The art has developed and the industry has extended with the art. It has been found that it is in the interest of the industry as well as of the community to have great central power stations, favorably located, supplying a large territorial district comprised of many communities, in place of the small individual plants for each community. The cost of power supply is reduced through these larger and more economic generating units. It has been found of advantage to the power companies to diversify the load by the different uses to which power is put in different communities at different times of the day. This, too, is of advantage to the power companies in that it makes their investment more productive. When, however, great districts are served by a single power company, when great power transmission lines are run through rural communities in order to connect one city with another, when the farms and small villages find that they can not tap these lines for service which run directly by their door, they begin to ask, and, in my judgment, properly ask why if they are a part of this great integrated power district, they should not have their service too. In other words, I think the power companies must remember that when they extend their operations over wider areas, and put their network of power lines over large districts, they take on an obligation to serve the people of the district in which they have the privilege of operating. This does not mean that they can run a service line to the last farm, or even the last village in that district, but it does mean that they must view their obligation as they have always done, as one having two aspects, one economic, and the other social. The company must neither ride the economic hobby to the point where its service is not generally available in the community, nor, on the other hand, can it ride the social hobby as some loud-speaking and visionary persons outside of the industry urge, to the point of financial bankruptcy. Wise human judgment must be exercised in the service of the citizens of the district in which the company operates, and I am happy to say, for the most part, the power companies have exercised such judgment, and that accounts largely for the high favor in which they are held and the stability of their business and their securities. I have never contended that a small plant in a small village, whose duty it was to supply the village, had any obligation to run a line 15 miles in the country to supply the farmers along that line. What I do say is that if a company sees fit to connect up 40 or 50 or 100 such cities and villages in its own interest, then its obligation, subject to the economic limitations mentioned earlier, is to supply that whole district electrically, not the cities alone, but the villages and agricultural areas as well within the field of their operations.

The fundamental limitation under which the power company can supply these services to the whole community is that the rates should be such that the earnings from the community as a whole will yield a fair return on the investment of the power company as a whole. Therefore, in my judgment, the rates should be studied from this point of view. The Public Service Commissions should co-operate, and even insist, upon their establishment. Rates so far as possible should be simplified. The slide rule after all is not as unerring as the engineer sometimes thinks, especially when we have to apply it to the social needs of a community in which human understanding and human sympathies must be mingled with economics and mathematics in order to get a practical result.

So I ask the power company which extends its lines over great areas and connects up many cities and towns to regard the farmer within that territory as one to whom it owes an obligation. If the power companies will recognize such obligation, then I ask them to study the farmers' needs and within every reasonable economic limitation to supply the service.

What Can the Manufacturer Do?

Now as to the manufacturer. He, too, is subject to the indictment of want of interest. He has sought to apply electricity to everything in the world except the farm. He has spent enormous sums on research and engineering to find out how to make industries more productive and economical. He has been unremitting in his toil to apply electricity to transportation, both on sea and land. He has been constant and devoted in his attention to every kind of device to make the turn-over and marketing of goods quicker and simpler and more profitable. I say the manufacturer has not yet met by sufficient expenditure of energy or money the problem of the farmer. Without electrical machinery adapted to farm use, the farmer cannot extend the use of electricity to his profit. Unless he can extend it to his profit, he will not use it, and unless he becomes a substantial consumer of power, it will be economically impossible for the power companies to supply the service. Therefore, the manufacturing companies must endeavor to develop these agricultural applications. The farmer must be open-minded enough to use them, and if these two things are done, the power companies, I am sure, can and will provide the lines. It is the manufacturer's job and his responsibility, and, so far as I am able to speak for the great concern with which I am proud to be connected, I pledge you now its co-operation and its effort in trying to answer the question before us.

What Can the State Do?

And now as to the State. What can it do? This is one field in which I have not had experience. Let me be very specific now and address myself to the State of New York. Nowhere else in the world are there such resources of waterpower contiguous to so great a market. The God-given storage of the great lakes and the drainage area of half a continent is collecting water and equalizing its flow over the falls of Niagara and down the rapids of the St. Lawrence, all for the economic benefit of the State of New York. All we have to do is to take advantage of it. Nature has done her share. Relatively small developments have been made. Millions of horse power run to waste every year. This waste takes place, not because the electrical art and industry can not harness these great powers; not because they are too timid to try. The record is that they have sought and are seeking the opportunity to develop these powers but as yet no adequate permits have been given. In addition to the great powers on the boundary streams, which are capable of carrying base load operations of the State, we have smaller powers in the Adirondacks, on the Genesee, and on the Delaware, which, with adequate storage, could be developed to carry the peak loads which occur at different hours during the day. These powers can be laid down on great busbars throughout the State and made available everywhere within the State. What would it mean to the Mohawk Valley if a million horse-power were to be laid down along its six tracks of railroad and the barge canal? Industries which have been seeking the cheap coal of Pennsylvania and the waterway of the lower Delaware, would find their way into the district in which I now stand. The increasing population of this district would enlarge the market for all the farms in this State. They would become more valuable instead of becoming less valuable. Our industries would be largely increased instead of standing more or less stationary. Still, the power which is necessary to do this job runs to waste. And why? It is because the people of the State of New York have permitted this great economic question to become a political football. One would think that all of the people of the State would demand such a simple and desirable development. When gold was discovered in Alaska, the front pages of the newspapers were filled, and thousands of men from all countries rushed to dig it out and increase their wealth. Yet here, we let gross values larger than all the gold in the world run to waste. These we could conserve for the benefit of the people of the State. For the farmers in better markets; for the workmen in better wages; for the industries in larger and more adequate power; for the railroads in better transportation.

Why is it? What are the slogans which mislead us? One is that the grasping power company is trying to destroy the scenic beauty of Niagara Falls, and yet I think I am right in saying the latest studies show that, in view of the erosion, scientific handling of the Falls must be had in order to preserve their beauty, and that it may be had consistent with great additional power development there.

Next time the slogan is the destruction of the Adirondack forest—the playground for the people. I yield to no one in my love for the Adirondacks and in my desire to preserve them. I think I know the needs of the power companies. I would not impair the beauty of that great playground to develop power, nor would I permit any people having special interests, whether they be political or otherwise, to prevent the adequate use of these powers for the benefit of all the people of the State under a visionary and unfounded cry of forest destruction. Are we so incompetent in this State, that we can not develop plans to conserve and use the waters of that great watershed for the benefit of all the people of the State without destroying or impairing in the least the beauty and the development of that great forest? Personally, I am sure we can.

And finally, the most effective slogan of all —the power trust is trying to steal these natural resources for its own benefit and take them away from the people. If there be a power trust, which I deny, most people would admit that I am competent to speak about it. It is evident that nobody can make a dollar out of these falling waters except by harnessing them for the service of the community. No capitalization of the developing company can be had and no rates can be charged except such as are approved by the Public Service Commission of the State. What is there to this charge of stealing the waterpowers if they can be developed only under State control, and if they can make their money only by rates approved by the State, and if their income can arise only from putting the power which is now going to waste to the service of the people?

For 25 years, we have permitted these great economic resources of the State of New York to run to waste while the politicians have played football with this subject. I propose that the people of the State demand now that this economic proposition be dealt with on an economic and sensible basis; that the powers be made available, and that we substitute economic progress for political horseplay.

As to St. Lawrence powers, I am happy to say that that problem is being studied by an international commission under the leadership of the Secretary of Commerce of the United States. No one is more competent to deal with that great question in the interest of all the people. The State of New York, however, is doing nothing to aid the Federal Government in trying to make those great powers available for its own people.

Now, I have not wandered so far away from the electrification of the farm, because the development of these great waterpowers is one of the ways in which not only industries may be enlarged, but the welfare of the farms may also be advanced. When we substitute the power of falling water for coal which we do not produce, and the transportation of which clogs our railroads, then we will make a great step forward in all electrification, and not the least, the electrification of the farm.

Electrification Economies on the Chicago, Milwaukee & St. Paul Railway

By W. D. Bearce

Railway Engineering Department, General Electric Company

A comparison of steam and electric railroad operating costs is always instructive and very helpful to railroads contemplating electrification. The Chicago, Milwaukee & St. Paul Railway has recently made a complete analysis of operation on its system and it is here presented in abstract.—Editor.

The electrification of the Chicago, Milwaukee & St. Paul Railway, in Montana, began with the section between Three Forks and Deer Lodge in December, 1915. Successive divisions were added to the electric zone during the year 1916, completing the present section in Montana from Harlowton to Avery, a distance of 438 miles. The 210-mile section between Othello and the Pacific Coast was electrified in the latter part of 1918. The initial zone, therefore, at the end of 1924 had been in operation approximately eight and one-half years, and the Coast Division nearly five years. The report of the comparative costs of electric and steam operation recently issued by H. E. Byram, President of the railway, was prepared by Chester E. Oliphant, Assistant to the Comptroller in charge of statistics under the direction of W. W. K. Sparrow, Vice-President, and in consultation with R. Beeuwkes, Electrical Engineer in charge of the installation.

This project is the most extensive operation of its kind ever undertaken, consisting of a total of 648 miles of main line, where all train movements including freight, passenger, and switching are handled exclusively by electric power. The installation has been studied by prominent engineers, commissions, and delegations from all parts of the world. The electrification has been pronounced an unqualified success from an operating standpoint, and all students of the project have expressed great interest in the question as to whether the expenditures for the electrification equipment have been justified by operating economies. Briefly stated, the outstanding fact brought out by this report is that with a net additional investment of $15,625,000 the saving to date over and above interest and carrying charges, has been $12,400,000.(1) That is to say, the reduction in the cost of operation has been sufficient to liquidate more than three-quarters of the initial outlay in addition to paying all interest and depreciation charges.

The sections between Harlowton and Avery, and between Othello and the coast were electrified at different times and have different physical and traffic characteristics as well as different investment costs. For this reason the report deals with the cost of steam and electric operation on each section separately. The total savings effected, however, as the result of electrification, are shown in Table I, which summarizes the data on all electrified sections.

---

(1) The actual savings over steam operation amount to 19,000,000.

The assumed cost of steam operation for the year 1923, had this form of operation been employed in the electric zone, is based on the actual cost of steam operation for the last 12 months such operation was in effect, adjusted to the conditions obtaining in 1923. The last year of steam operation in the case of the Harlowton-Avery section was the year ending December, 1915, and for the coast division the year ending July 31, 1919.

TABLE I

NET SAVINGS AND VOLUME OF TRAFFIC DURING ELECTRICAL OPERATION

Years	HARLOWTON TO AVERY Electrical Operation began April and Nov., 1916		OTHELLO TO TACOMA Electrical Operation began March, 1920		ALL ELECTRIFIED SECTIONS	
	Volume of Traffic Gross Ton-miles Frt. and Pass.	Net Savings by Electrification	Volume of Traffic Gross Ton-miles Frt. and Pass.	Net Savings by Electrification	Volume of Traffic Gross Ton-miles Frt. and Pass.	Net Savings by Electrification
1916	1,639,054,000 (a)	$1,098,166 (a)			1,639,054,000	$ 1,098,166
1917	2,677,097,000	1,641,369			2,677,097,000	1,641,369
1918	2,759,178,000	1,734,687			2,759,178,000	1,734,687
1919	2,894,063,000	1,888,037			2,894,063,000	1,888,037
1920	2,710,745,000	1,679,623	691,674,000 (b)	$249,003 (b)	3,402,419,000	1,928,626
1921	1,812,714,000	658,651	664,238,000	12,363	2,476,952,000	671,014
1922	2,109,868,000	996,485	734,121,000	103,301	2,843,989,000	1,099,786
1923	2,247,102,000	1,152,508	746,405,000	119,285	2,993,507,000	1,271,793
1924	2,129,426,000	1,018,721	691,476,000	47,808	2,820,902,000	1,066,529
Total		$11,868,247		$531,760		$12,400,007

(a) Tonnage and savings for 6½ months.
(b) Tonnage and savings for 9 months.

Under either method of operation some costs, within reasonable limits, remain constant while others vary with the volume of traffic. Because the total tonnage moved in each year was different, the unit cost, or cost per gross ton-mile, as found for the tonnage handled in the selected years of steam operation is not comparable with the cost per gross ton-mile as found for the tonnage handled in the year of electrical operation. In order, therefore, to make a comparison and determine the difference in cost between the two methods of operation, the costs as developed for the traffic any one year had to be adjusted to conform to the volume of traffic of the other years. This adjustment was made by separating the costs between those which, within practical limits for the range of tonnage under consideration, vary directly with the volume of traffic and those which remain constant. When this has been done it is a simple matter to state the cost of steam operation for the tonnage of the year of electrical operation, and similarly, the cost of electrical operation for the tonnage of the years of steam operation. The only assumption made in this adjustment is that the costs as separated between constant and variable have true varying and constant characteristics. In the case of the Rocky Mountain and Missoula Divisions where there was little variation in the volume of tonnage as between the selected year of steam operation and electrical operation, this is within practical limits a true assumption, and any possible variation would be slight and of no consequence. In the case of the Coast Division where the tonnage in the year of electrical operation was very low in comparison with the tonnage of the steam period, any variation from the assumption made would have the effect of making the unit costs of electrical operation for the higher tonnages as shown in this report greater than they should be, and consequently make the net savings less than they should be.

Due to the difference in the cost levels obtaining in the different years in which the property not common to both uses was acquired, there is considerable difference in the investment cost of such property. As interest and depreciation charges on all property used solely for either operation are in this report charged against the form of operation to which they apply, it is just as necessary to a true comparison of cost to restate such investment costs for a period having the same cost levels as it was to restate the cost of labor and material used in operation. This has been done, using for the electrical property the actual cost figures and for the steam property no longer in use on the electrified sections and which consequently has either been released for use on other divisions of the railroad or retired from service, the cost which such property would have represented if new at the time of the purchase and installation of the electrical property.

No savings have been credited to electrical operation which are not susceptible of direct ascertainment, as for example, the possible increased revenue due to the released equipment used in transportation of coal when these divisions were under steam operation. Other economies of this sort include better utilization of freight equipment, due to faster movement, less wear and tear on road and equipment, less station expenses and similar expenses affected by the number of trains required to handle a given tonnage, increase in passenger revenue due to the attractiveness and greater comfort of travel under electrified operation.

Features of Electrification

Contracts for the initial electric zone from Three Forks to Deer Lodge were closed in October, 1914. Subsequent contracts included

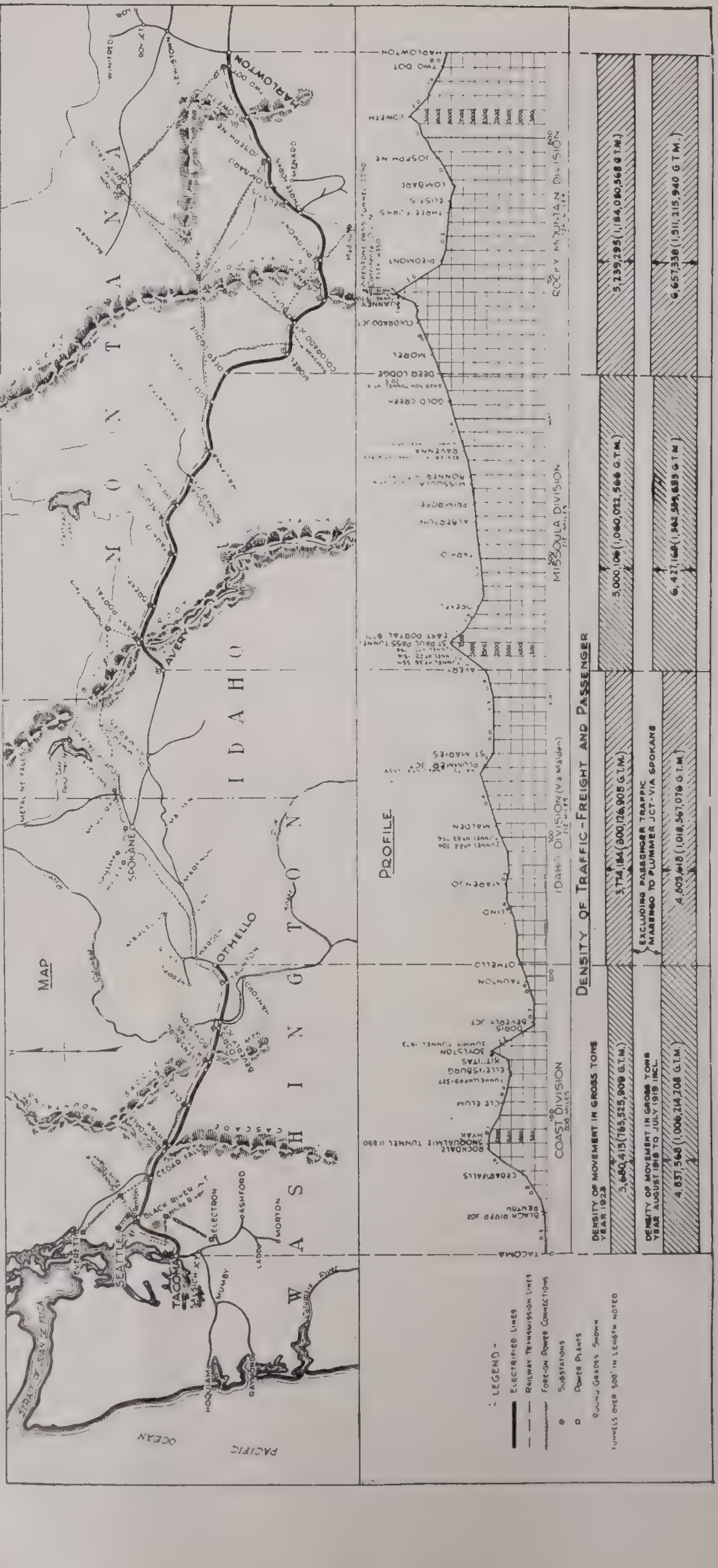

MAP
PROFILE
DENSITY OF TRAFFIC–FREIGHT AND PASSENGER
MONTANA
IDAHO
WASHINGTON
PACIFIC
OCEAN
SEATTLE
TACOMA
OTHELLO
SPOKANE
AVERY
HARLOWTON
COAST DIVISION
IDAHO DIVISION
MISSOULA DIVISION
ROCKY MOUNTAIN DIVISION
DENSITY OF MOVEMENT IN GROSS TONS YEAR 1923
DENSITY OF MOVEMENT IN GROSS TONS YEAR AUGUST 1918 TO JULY 1919 INCL.
EXCLUDING PASSENGER TRAFFIC MARENGO TO PLUMMER JCT–VIA SPOKANE
- LEGEND -
ELECTRIFIED LINES
RAILWAY TRANSMISSION LINES
FOREIGN POWER CONNECTIONS
SUBSTATIONS
POWER PLANTS
RULING GRADES SHOWN
TUNNELS OVER 500' IN LENGTH NOTED

Fig. 1. Topographical Features of the Western Portion of the Chicago, Milwaukee & St. Paul Railway. The heavy line on the map indicates electrified divisions. The profile shows heavy grades on which electric locomotives have proved far superior to steam

equipment for the balance of the 438 miles of line between Harlowton and Avery.

The direct-current 3000-volt system was selected, using overhead distribution supported on wood poles. Current is purchased from the Montana Power Company which taps the Railway Company's 100,000-volt line at several points. Along this line are 14 substations in which the supply is stepped down to 2300 volts and then converted by means of motor-generator sets to 3000 volts direct current.

The orders placed with the General Electric Company for the initial equipment included 42 main line locomotives, 12 of which were equipped with oil-fired boilers for train heating and suitable gearing for handling passenger trains. Two switching locomotives were also ordered.

For substation equipment, apparatus was furnished by the same company for 14 substations spaced approximately 30 miles apart, including motor-generators, transformers and switching equipment.

The overhead line construction was also designed by the General Electric Company, being the first example of a twin trolley supported at alternating points to secure a flexible contact.

All locomotives were equipped for regenerative electric braking for holding trains on the long two per cent grades, without the use of air.

Equipment for the electrification of the Coast Divisions was ordered in 1918 and included 8 substations, 15 passenger locomotives and two switchers. For freight service the 12 geared units originally used in passenger service on the Rocky Mountain Divisions were changed to freight gear ratio, and 10 of the new passenger locomotives were assigned to the initial electric zone.

The lengths of the sections now electrified and the dates when the different sections were placed under electrical operation are given in Table II.

The sections of line between Black River Jct. and Seattle, a distance of 10 miles, and between Avery and Othello via Malden, a distance of 212 miles, will without doubt be electrified in the future as electrical operation will not only effect savings on these sections but the continuity resulting will augment the savings on all of the present electrified sections.

A summary of the economies resulting from electrification is given in Table I. This table shows the net savings for each year since the beginning of electrical operation using for steam operation the actual costs for the last 12 months of such operation, adjusted to 1923 levels. For electrical operation the actual costs are used for the year 1923. From this table it may be seen that the net savings for the year 1923 were approximately $1,250,000. This was a year of comparatively low tonnage and the report calculates that for the year 1919 which showed maximum tonnage for the period under discussion the savings over the entire electric zone would have amounted to $2,355,000 had the Othello-Tacoma section at that time been under electrical operation. On the other hand, the savings shown for the minimum tonnage year for 1921 indicate a gross saving of $671,000.

TABLE II

	MILES OF TRACK		Operation Dates
	First Main	Other	
Harlowton to Deer Lodge..........	226	66	Apr., 1916
Deer Lodge to Avery..........	212	62	Nov., 1916
Othello to Tacoma (helper service)..	...	..	Aug., 1919
Othello to Tacoma (through service).	208	72	Mar., 1920
Tacoma Jct. to Tacoma (pass.)....	2	..	Sept., 1920
	648	200	

The differences in costs and in distribution of costs, as of the year August, 1918, to July, 1919, inclusive, are shown in Table III. These figures include only the operating expenses directly affected by change in power and the carrying charges on investment in the property directly involved. Operating expenses common to both methods of operation and carrying charges on the investment in the property used common to both electrical and steam operation are excluded from all comparisons.

The charts in Figs. 2 and 3 show graphically the comparative costs of electrical and steam operation per 1000 gross ton-miles, taking into account the operating expenses directly affected by the change in the method of operation, and the carrying charges on the investment in property used solely for either steam or electrical haulage. It will be noted that in Fig. 2, showing expenses for the Harlowton-Avery section, the volume of traffic was slightly higher in 1923 than in 1915, the year of initial operation. In Fig. 3, however, showing the same data on the Othello-Tacoma section the volume of traffic during the electrical period was only about 75 per cent of that during the last year of steam operation. Figs. 4 and 5 show graphically the savings in operating expenses for the two electric zones respectively.

STATISTICS OF ELECTRICAL AND STEAM OPERATION

As previously stated, the costs of operation for the purpose of the report include only the costs in operating expenses directly affected by the change in method of operation and the carrying charges on the investment in property necessary to one form of operation but unnecessary to the other, i.e., property not common and necessary to both methods of operation. No useful purpose would have been served by including in this comparison either operating costs common to both steam and electrical operation and which vary from year to year from causes in no way related to the kind of power used, or carrying charges on investment in property common and necessary to both forms of operation.

Operating Expenses Directly Affected by Change In Power

The selection of accounts used was made after a careful study of the expenditures under each of the primary accounts of the operating classification. Some of the accounts excluded as not being affected by change in power are without doubt affected to some extent by change in power, but the effect is so slight as to be negligible in comparison with the effects produced by other causes. Take for example, "Maintenance of Track," an expense unquestionably affected to some extent by the class of power. The effects from other causes such as weather, availability of money, cycles of renewals of parts, maintenance programs, labor condi-

TABLE III

COMPARISON OF COST OF ELECTRIC AND STEAM OPERATION AS OF THE YEAR AUGUST, 1918, TO JULY, 1919, INCLUSIVE

	ROCKY MT. DIVISIONS		COAST DIVISION	
	Steam	Electric	Steam	Electric
Gross ton-miles pass. and fgt.	2,864,695,000	2,864,695,000	1,014,511,000	1,014,511,000
EXPENSES RELATED TO POWER				
Locomotives				
Carrying charges on investment	178,383	$240,694	$193,511	$296,273
Maint. cost incl. maint. of shops	1,268,824	440,833	496,016	194,912
Housing and hostling cost	281,396	102,736	82,056	39,715
Cost of lubrication and other supplies for locomotives	57,585	28,030	18,385	16,815
FUEL: ELECTRICITY				
Cost of coal, oil, water and electric current	1,606,507	851,908	721,878	414,403
Carrying charges on investment in facilities	48,195	484,169	43,857	451,427
Maintenance cost of facilities	33,730	86,352	13,488	46,985
COST OF ENGINEMEN AND MOTORMEN	733,070	411,508	328,626	185,886
TRAIN AND YARD EXPENSES				
Cost of trainmen and yardmen	639,144	412,453	374,297	227,211
Train and yard supplies and exp. including brake shoe, wheel and draft rigging wear	42,014	13,211	25,314	7,785
SIGNAL AND INTERLOCKER EXPENSES				
Carrying charges on investment		(Net) 11,246	43,513	55,458
Cost of maintenance	52,131	47,671	33,202	31,343
Cost of operation	40,841	31,517	19,248	14,380
WORK TRAIN EXPENSE				
Equal amount of work both periods	74,721	62,415	50,452	39,676
Expense of superintendence	284,906	262,055	114,497	106,209
Total expenses and charges	5,341,447	3,486,798	2,558,340	2,128,478
NET SAVINGS BY ELECTRIFICATION	1,854,649		429,862	

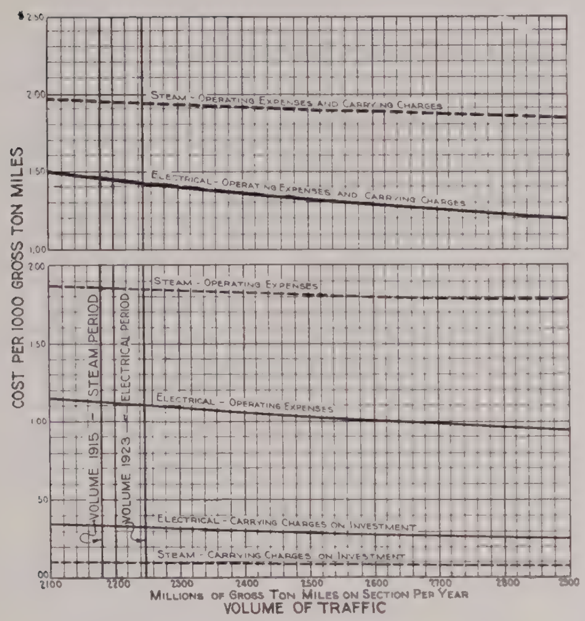


Fig. 2. Rocky Mountain and Missoula Divisions

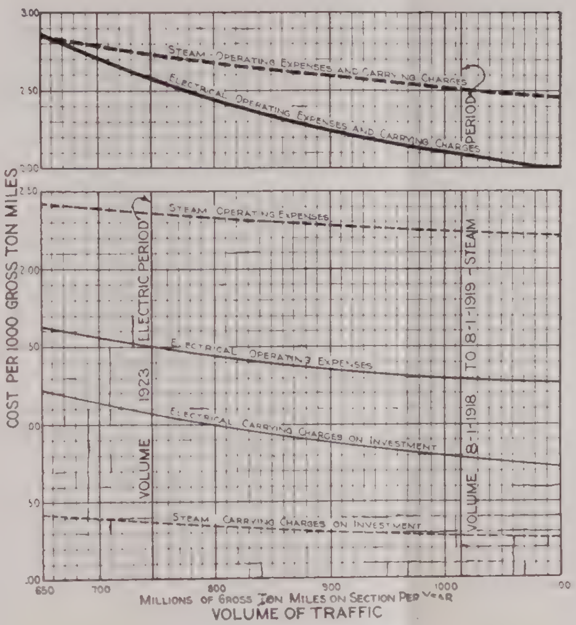


Fig. 3. Pacific Coast Division

Comparative Costs of Steam and Electric Operation Over a Period of One Year

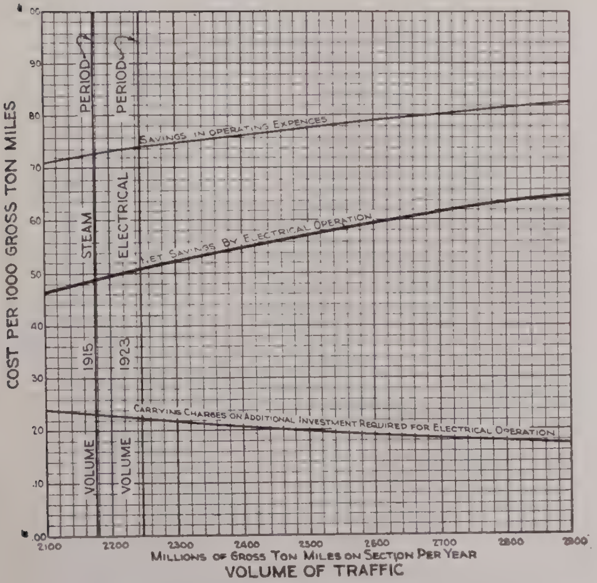


Fig. 4. Rocky Mountain and Missoula Divisions

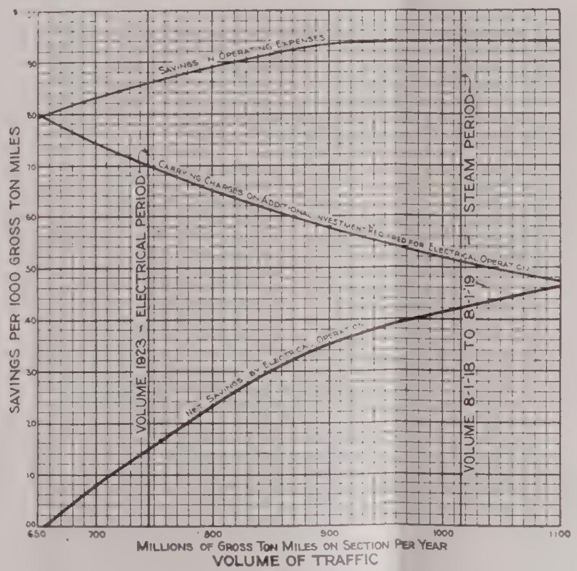


Fig. 5. Pacific Coast Division

Savings Effected by the Adoption of Electric Haulage Over a Period of One Year

I.C.C. Accts. (1)	Classification of Expenses Description (2)	HARLOWTON TO AVERY						OTHELLO TO TACOMA					
		STEAM OPERATION Costs of the Year 1915 Adjusted to the Price Levels of 1923			ELECTRICAL OPERATION Actual Costs of the Year 1923			STEAM OPERATION Costs of the Year, August, 1918, to July, 1919, inclusive, Adjusted to the Price Levels of 1923			ELECTRICAL OPERATION Actual Costs of the Year 1923		
		Variable (a)		Constant (a) Frt. & Pass. (5)	Variable (a)		Constant (a) Frt. & Pass. (8)	Variable (a)		Constant (a) Frt. & Pass. (5)	Variable (a)		Constant (a) Frt. & Pass. (8)
		Freight (3)	Passenger (4)		Freight (6)	Passenger (7)		Freight (3)	Passenger (4)		Freight (6)	Passenger (7)	
	Maintenance of Way and Structures												
201	Superintendance			$ 94,472			$ 95,208			$ 48,295			$ 49,777
231	Water stations			23,800						8,273			
233	Fuel stations			9,930						5,215			
235	Shops and enginehouses			42,383			33,927			16,234			12,513
249	Signals and interlockers			52,131			47,671			33,202			31,343
255	Power substation buildings						1,530						2,047
257	Power transmission systems						2,913						5,179
259	Power distribution systems						40,763						19,723
261	Power line poles and fixtures						18,379						11,066
271	Small tools and supplies (for M. of elec. prop. only)						847						365
	Total maintenance of way and structures			$222,716			$ 241,238			$111,219			$132,013
	Maintenance of Equipment												
301	Superintendance			$120,194			$ 105,440			$ 31,105			$ 22,306
306	Power substation apparatus						19,163						7,891
308–11	Locomotive repairs—train	$ 687,824	$218,725		$ 190,390	$135,349		$ 326,467	$ 129,174		$ 78,549	$ 60,703	
308–11	Locomotive repairs—switch	37,105			12,510	77		24,141			2,658		
314–17	Brake shoe and rigging, wheel and draft rigging wear	21,352	11,622					18,000	7,000				
326	Trolley maintenance cars—only						2,757						714
	Total maintenance of equipment	$ 746,281	$230,347	$120,194	$ 202,900	$135,426	$ 127,360	$ 368,608	$ 136,174	$ 31,105	$ 81,207	$ 60,703	$ 30,911
	Transportation												
371	Superintendance			$ 70,240			$ 61,407			$ 35,097			$ 34,126
377	Yardmasters and yard clerks			17,055			17,055			6,708			3,268
378	Yard conductors and brakemen	$ 61,533			$ 27,174	$ 166		$ 40,560			$ 10,038		
379	Yard switch and signal tenders			1,189			548			2,047			578
380–81	Yard enginemen—yard motormen	39,644			17,990	110		25,629			6,396		
382–84	Fuel for yard locos.—yard switch. power purchased	43,315					9,489	24,763					2,714
383	Yard switching power produced						1,053						447
385	Water for yard locomotives	1,257						602					
386	Lubricants for yard locomotives	777			394	1		506			105		
387	Other supplies for yard locomotives	808			302	1		526			44		
388	Enginehouse expense—yard	12,431			4,131	25		6,845			1,186		
389	Yard supplies and expenses			712			328			314			62
392–93	Train enginemen—train motormen	400,421	121,341		231,352	77,778		233,323	69,674		92,224	38,095	
394–96	Fuel for train locos.—train power purchased	886,009	270,693				754,231	493,807	186,446				319,634(c)
395	Train power produced						87,135						53,301
397	Water for train locomotives	24,939	7,556					11,710	4,548				
398	Lubricants for train locomotives	14,534	3,360		9,979	4,811		5,606	1,758		4,804	2,171	
399	Other supplies for train locomotives	19,018	5,381		4,831	2,470		7,211	2,778		3,485	1,999	
400	Enginehouse expense—train	142,283	66,330		42,341	40,531		45,959	29,252		14,554	16,127	
401	Trainmen	317,041	94,649		197,067	94,649		264,338	60,644		107,183	47,698	
402	Train supplies and expenses (train—light and heat)					12,883						7,723	
404	Signal and interlocker operation			40,841			31,517			19,248			14,380
	Total transportation	$1,964,010	$569,310	$130,037	$ 535,561	$233,425	$ 962,763	$1,161,385	$ 355,100	$ 63,414	$240,019	$113,813	$428,510
	Work Train Expense—All other than included above in M. of W. & S. adjusted to 1923 work train miles			$ 74,721			$ 62,415			$ 50,452			$ 39,676
	TOTALS FOR OPERATING EXPENSES DIRECTLY AFFECTED	$2,710,291	$799,657	$547,668	$738,461	$368,851	$1,393,776	$1,529,993	$ 491,274	$256,190	$321,226	$174,516	$631,110
	Grand totals	$4,057,616			$2,501,088			$2,277,457			$1,126,852		
	GROSS TON-MILES IN THOUSANDS—THE WORK PERFORMED	1,758,726	419,905 (b)		1,827,197	419,905		805,830	208,681(d)		537,724	208,681	
	Grand totals	2,178,631			2,247,102			1,014,511			746,405		
	COST PER 1,000 GROSS TON-MILES	$ 1.54105	$1.90438		$ 0.40415	$0.87842		$ 1.89865	$ 2.35419		$0.59738	$0.83628	

(a) "Variable"—Expenses considered to vary practically directly with volume of traffic: "Constant"—Expenses considered to remain practically constant for all volumes of traffic within a reasonable range.

(b) The actual for the period, 354,054,000, adjusted to the tonnage of electrical operation as the difference rests solely in the number of cars per train: Expenses adjusted to conform.

(c) Constant up to a total of 906,097,000 gross ton-miles for freight and passenger services; thence increased in freight service as estimated necessary for greater volumes of traffic: (The amount to be added at 1,014,511,000 g. t-m. is $3[illegible],307.00.)

(d) The actual for the period, 186,232, adjusted to the tonnage of electrical operation as the difference rests solely in the number of cars per train due to difference in train tions, etc., are so much greater and so impossible of exact ascertainment for elimination, that the expense can only be classified as not being affected by change in power. Work train expenses have been separated and included as expenses directly affected by change in power for several reasons, one of which is that certain stand-by losses under steam operation are eliminated by using electric motors in work train service. The costs of the two periods have been adjusted to the same amount of work-train service.

All costs in the following statements in the totals are for periods of one year. For the section, Othello to Tacoma, the steam operating costs are derived by an exhaustive analysis of the operating expenses of the year August 1, 1918, to August 1, 1919—the last year of steam operation before electrification. For the section, Harlowton to Avery, the steam operating costs are based upon the operating expenses of the year 1915, except that where these expenses were known to be incomplete as for some of the minor items, recourse was made to the unit costs of steam operation on the adjacent steam operated divisions. For both sections, the electrical operating costs are the actual costs for the year ending December 31, 1923.

As the price levels of labor and material were not the same for the periods of electrical and steam operation, it was necessary to bring the costs to the same level so that a true comparison could be made. To this end the costs of the steam periods have been restated as of the electrical period and hence all the operating expense costs in this report are for the price levels of 1923.

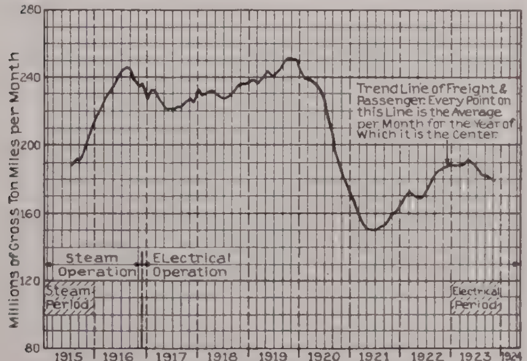


Fig. 6. Annual Variation of Total Traffic Between Harlowton and Avery

The two cross-sectioned rectangles designate the periods from which the report figures were computed.

With respect to the savings through the use of regenerative electric braking, it was found that no existing data were available which would enable the brake shoe wear to be determined with any accuracy for the condition of continuous and long application which, under steam operation, occurs on mountain grades. Therefore, a wear figure, believed at least to be conservative, of one pound of wear per 100,000,000 ft.-lb. of energy dissipated was used. There is also a saving in draft rigging and braking apparatus and in wheel wear, all of which are, for evident reasons where cars move over many divisions, indeterminable. The amount of savings on account of these items was assumed to be the same as that resulting from the reduction in brake shoe wear. This is believed to be conservative.

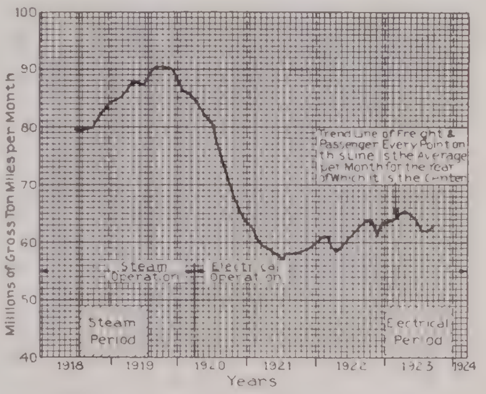


Fig. 7. Annual Variation of Total Traffic Between Othello and Tacoma

The two cross-sectioned rectangles designate the periods from which the report figures were computed.

Costs of electric power are based upon a minimum total payment corresponding to the respective kilowatts for which the Railway Company in 1913 had for the different respective sections exercised option. Where these respective amounts of kilowatts are not sufficient to handle the increased traffic, power cost has been increased on basis of the additional kilowatts required.

Constant and Varying Operating Expenses

The total tonnage moved in the selected years, or any year that could have been selected, for steam operation was not the same as the tonnage moved in the year of electrical operation. Therefore, in order that the costs of electrical and steam operation might be stated for different volumes of traffic, within a reasonable range of the tonnage which has been handled over these divisions, without which a correct comparison between the cost of steam and electrical operations could not be made, the costs affected by a change from steam to electrical operation were separated between those which within reasonable limits remain constant for different volumes of traffic, because they are not connected with the direct movement of traffic, and those which on account of being directly connected with the movement of traffic vary directly with the volume of traffic. These latter expenses have further been separated between the passenger and freight services, as such expenses can be directly assigned. With these separations in the expenses, the costs of operation for the volumes of traffic dealt with in this report may be readily obtained: It is only necessary to multiply the gross ton-miles of each service at any volume point by the respective unit costs developed, and to the sum of the products so derived add the total constant cost.

TABLE V

INVESTMENT IN AND CARRYING CHARGES ON THE PROPERTY PECULIAR TO EACH MODE OF OPERATION

Items	**HARLOWTON TO AVERY** (438 Roadway Miles)				**OTHELLO TO TACOMA** (208 Roadway Miles)			
		CARRYING CHARGES				CARRYING CHARGES		
	Investment (a)	Interest 5%	Depreciation S. F. Basis 6%	Total	Investment (c)	Interest	Depreciation S. F. Basis 6%	Total
Steam Operation								
Fixed Property:								
Fuel and water stations, cinder pits, etc.	$ 630,000 (b)	$ 31,500	$ 16,695	....	$ 507,010	$ 30,421	$ 13,436	....
D-c. signal system	....	....	....	....	612,000	36,720	6,793	....
Totals—fixed property	$ 630,000	$ 31,500	$ 16,695	$ 48,195	$ 1,119,010	$ 67,141	$ 20,229	$ 87,370
Locomotives								
Freight (incl. all pusher and work service locomotives)	$ 2,470,628	$ 123,531	$ 28,165	....	$ 2,135,785	$ 128,147	$ 24,348	....
Passenger	356,039	17,802	4,059	....	430,231	25,814	4,905	....
Switch	78,598	3,930	896	....	144,224	8,653	1,644	....
Totals—locomotives	$ 2,905,265	$ 145,263	$ 33,120	$ 178,383	$ 2,710,240	$ 162,614	$ 30,897	$ 193,511
TOTALS—STEAM PROPERTY	$ 3,535,265	$ 176,763	$ 49,815	$ 226,578	$ 3,829,250	$ 229,755	$ 51,126	$ 280,881
Electrical Operation								
Fixed Property:								
Roadway buildings	$ 89,545	4,477	2,382	....	114,215	$ 6,853	$ 3,027	....
Power substation buildings	535,157	26,758	3,361	....	452,808	27,168	2,875	....
Power substation apparatus	1,859,353	92,968	21,383	....	1,476,964	88,618	16,985	....
Power transmission system	715,181	35,759	5,435	....	549,521	32,971	5,072	....
Power distribution system	2,890,615	144,531	23,269	....	2,190,401	131,424	16,822	....
Power line poles and fixtures	1,091,721	54,586	50,110	....	966,563	57,994	40,596	....
A-c. signal system	197,446 (b)	9,872	1,374	....	780,000	46,800	8,658	....
Engr.—int. during construction and miscl.	325,671	16,284	3,354	....	621,519	37,291	7,645	....
Maintenance equipment	37,000	1,850	422	....	27,000	1,620	308	....
Sub-total	$ 7,741,689	$ 387,085	$111,090	$ 498,175	$ 7,178,991	$ 430,739	$101,988	$ 532,727
Rental of transmission lines credit	....	$Cr. 2,760	....	$Cr. 2,760	....	$Cr. 25,842	....	$Cr.25,842
Totals—fixed property	$ 7,741,689	$ 384,325	$111,090	$ 495.415	$ 7,178,991	$ 404,897	$101,988	$ 506.885
Locomotives								
Freight (incl. all pusher and work service locomotives)	$ 2,881,112	$ 144,056	$ 32,845	....	$ 3,065,280	$ 183,917	$ 34,944	....
Passenger	927,408	46,370	10,573	....	1,035,690	62,141	11,807	....
Switch	111,564	5,578	1,272	....	48,520	2,911	553	....
Totals—locomotives	$ 3,920,084	$ 196,004	$ 44,690	$ 240,694	$ 4,149,490	$ 248,969	47,304	$ 296,273
TOTALS—ELECTRICAL PROPERTY	$11,661,773	$ 580,329	$155,780	$ 736,109	$11,328,481	$ 653,866	$149,292	$ 803,158
INCREASE IN CARRYING CHARGES ACCOUNT ELECTRIFICATION	....	....	....	$ 509.531	....	....	....	$ 522,277

(a) Electrical operating property at actual cost 1914-15-16: Steam operating property priced as of the costs obtaining during the same period (1915).

(b) Net increase in investment chargeable to electrification included under electrical operation.

(c) Electrical operating property at actual cost 1917-18-19: Steam operating property priced as of the costs obtaining during the same period (1918).

Carrying Charges on Investment in Property

The property here considered is the power equipment and the facilities and appurtenances directly related thereto—as for example in steam operation, the fuel and water stations; and in electrical operation, the transmission and distribution systems, substations, etc. The signal systems are also included as it was necessary to change the d-c. systems for a-c. systems on account of the electrification.

Investment for the property peculiar to electrical operation was taken as of the actual cost of installation—on the Coast Division, as of the prices obtaining in 1918 (1917 to 1919); on the Rocky Mountain and Missoula Divisions, as of the prices obtaining in 1915 (1914 to 1916). The investment in the property peculiar to steam operation was based upon the actual costs modified and adjusted to the price levels as of the periods of electrical installations—on the Coast Division,

TABLE VI

MOVEMENT AND FUEL STATISTICS OF THE TWO MODES OF OPERATION

Items	HARLOWTON TO AVERY					OTHELLO TO TACOMA				
	Freight	Passenger	Switch	Work	Total	Freight	Passenger	Switch	Work	Total
MOVING STATISTICS										
Steam Operation										
Gross ton-miles —total	1,792,366,000	419,905,000(a)	....	....	2,212,271,000	817,331,308	208,681,246(c)	....	....	1,026,012,554
Gross ton-miles —fuel	33,640,000	....	....	....	33,640,000	11,500,512	....	....	....	11,500,512
Gross ton-miles —(excl. fuel)	1,758,726,000	419,905,000	....	....	2,178,631,000	805,830,796	208,681,246	....	....	1,014,512,042
Car-miles—total	51,516,377	5,998,644	....	....	57,515,021	19,880,165	2,943,318	....	....	22,823,483
Car-miles—fuel	745,668	....	....	....	745,668	166,191	....	....	....	166,191
Car-miles—(excl. fuel)	50,770,709	5,998,644	....	....	56,769,353	19,713,974	2,943,318	....	....	22,657,292
Train-miles	1,198,113	652,507	....	....	1,850,620	497,885	303,822	....	....	801,707,
Locomotive-miles	1,717,981	775,969	152,429(b)	62,415	2,708,794	651,438	400,711	99,308(d)	38,420	1,189,877
Electrical Operation										
Gross ton-miles	1,827,197,000	419,905,000	....	....	2,247,102,000	537,723,988	208,681,246	....	....	746,405,234
Car-miles	49,526,372	5,998,644	....	....	55,525,016	14,706,709	2,943,318	....	....	17,650,027
Train-miles	741,475	652,507	....	....	1,393,982	285,321	303,822	....	....	589,143
Locomotive-miles	997,666	659,472	70,259(b)	62,415	1,789,812	404,678	310,355	23,711(d)	38,420	777,164
FUEL STATISTICS										
Steam Operation										
Gallons of oil	12,404,242	3,903,582	537,943	394,483	17,240,250	9,984,653	4,774,002	127,612	450,051	15,336,318
Tons of coal	132,900	39,113	7,394	1,665	181,072	42,702	8,423	4,571	....	55,696
Electrical Operation										
Kw-hr. gross consumption at locos	55,068,970	17,030,803	812,938	1,296,505	74,209,216	19,614,570	8,196,184	195,182	633,760	28,639,696
Kw-hr. total regeneration	6,375,350	2,313,040	....	29,130	8,717,520	3,399,260	1,341,370	....	8,340	4,748,970
Kw-hr. net consumption at locos	48,693,620	14,717,763	812,938	1,267,375	65,491,696	16,215,310	6,854,814	195,182	625,420	23,890,726
Kw-hr. at Power Co. Tap	75,850,552	23,017,585	1,230,607	1,977,284	102,076,028	26,269,144	10,990,981	316,406	1,002,470	38,579,001

(a) The actual for the period, 354,054,000, adjusted to the tonnage ot electrical operation as the difference rests solely in the number of cars per train: Car-miles, train-miles, and fuel adjusted to conform.

(b) The mileage of switching locomotives whether steam or electric is credited at 6 miles per hour while a crew is assigned to the engine. The great reduction in the figures for switching mileage, therefore, indicates a reduction in the number of locomotive hours in the ratio of 2 to 1 even with an appreciable increase in gross ton-miles of total traffic. This gives a measure of the superior capabilities of the electric unit.

(c) The actual for the period, 186,232, adjusted to the tonnage of electrical operation as the difference rests solely in the number of cars per train due to difference in train routing: Car-miles, train-miles, and fuel adjusted to conform.

(d) See note (b). On this division the reduction in switching locomotive hours is in the ratio of 4 to 1 with a corresponding decrease in gross ton-miles of traffic in the ratio of 1⅓ to 1.

as of 1918 and on the Rocky Mountain and Missoula Divisions, as of 1915.

The carrying charges computed upon the investments and included as cost are interest and depreciation. The interest rate has been taken at the rate paid by the St. Paul during the different periods of installation—for the Coast Division 6 per cent and for the Rocky Mountain and Missoula Divisions 5 per cent. Depreciation has been computed upon the sinking fund basis using an interest rate of 6 per cent.

Conclusion

Conclusions as to comparative cost of electrical and steam operation cannot be properly drawn from these primary cost statements as the comparative costs given therein are for different volumes of traffic. Further adjustments of the costs are necessary to equalize for the differences in volume of traffic before a true comparison is afforded. Such adjustments have been made in producing the curves shown in the charts (Figs. 2, 3, 4, 5) and in the statement of savings given in Table I.

TABLE VII

POWER EQUIPMENT OF THE TWO MODES OF OPERATION

Kind of Operation Class of Service	HARLOWTON TO AVERY						OTHELLO TO TACOMA					
	Class of Locos	Equiv. Number Assigned for Year	Weight Each in Working Order Pounds	TOTAL TRACTIVE EFFORT CAPACITY POUNDS			Class of Locos	Equiv. Number Assigned for Year	Weight Each in Working Order Pounds	TOTAL TRACTIVE EFFORT CAPACITY POUNDS		
				Maximum Starting	Hourly Rating	Continuous Rating				Maximum Starting	Hourly Rating	Continuous Rating
Steam Operation												
Freight service.. (Including all pusher and work service locomotives)	G-5	0–5/12	170,600	8,746	....	....	A-1	1/12	268,764	1,298	....	....
	K-1	43	360,000	1,432,760	....	....	C-3	2/12	362,530	7,530	....	....
	L-1	18–9/12	414,500	874,313	....	....	F-3	1/12	385,300	2,655	....	....
	L-2	5–2/12	431,000	282,720	....	....	F-4	9/12	383,350	27,368	....	....
	N-1	18–3/12	555,700	1,390,650	....	....	G-5	8/12	170,600	13,994	....	....
	N-2	11–8/12	561,700	889,000	....	....	G-6	6/12	309,600	12,720	....	....
							K-1	8– 2/12	360,000	272,114	....	....
							L-1	2– 9/12	414,500	128,233	....	....
							L-2	1– 5/12	431,000	77,522	....	....
							M-2	2/12	264,500	5,038	....	....
							N-1	10–11/12	555,700	831,853	....	....
							N-2	10	561,700	762,000	....	....
Total freight service .	......	97–3/12	....	4,878,189	....	....	.....	35– 8/12	....	2,142,325	....	....
Passenger service	F-3	1	385,300	31,870	....	....	C-2	11/12	350,250	39,253	....	....
	F-4	10	383,350	364,900	....	....	F-3	1– 5/12	385,300	45,150	....	....
	F-5	4	396,400	159,520	....	....	F-4	5– 8/12	383,350	206,778	....	....
							L-1	1/12	414,500	3,884	....	....
							N-1	3/12	555,700	19,050	....	....
Total passenger service	......	15	....	556,290	....	....	......	8– 4/12	....	314,115	....	....
Switching service	I-5	4	237,400	112,640	....	....	I-5	4– 9/12	237,400	133,760	....	....
	K-1	1–4/12	360,000	44,427	....	....	..	....	....	....	....	....
Total switching service..	......	5–4/12	....	157,067	....	....	......	....	....	....	....	....
TOTALS FOR STEAM OPERATION....	......	117–7/12	....	5,591,546	....	....	......	48– 9/12	....	2,590,200	....	....
Electrical Operation												
Freight service. (Including all pusher and work service locomotives)	E-F1	26	578,000	3,510,000	2,197,000	1,838,200	EF-1	16	578,000	2,160,000	1,352,000	1,131,200
Passenger service	EP-3	8	631,000	992,000	528,000	392,000	EP-2	5	558,200	572,250	242,500	210,000
Switching service	ES-2	3	140,000	126,000	63,000	42,000	ES-2	2	140,000	42,000	21,000	14,000
TOTALS FOR ELECTRICAL OPERATION.........	......	37	....	4,628,000	2,788,000	2,272,200	......	22	....	2,774,250	1,615,500	1,355,200

NOTE.—Power equipment of the two modes of operation equalized to handle the same maximum amount of traffic.

Comparative Cost of Steam and Electric Operation

By A. H. Armstrong

Railway Engineering Department, General Electric Company

We are presenting on page 218 of this issue the abstract of a report recently compiled by the Chicago, Milwaukee & St. Paul Railway, comparing steam and electric operation on the mountain divisions of its main line. This abstract, which was prepared by Mr. W. D. Bearce, is taken directly from the railway company's report, and attempts no additional comment. The article by Mr. Armstrong, here presented, goes a step further and offers an analysis of the data in so convincing a manner that there is small doubt left as to the financial and operational advantages of electric haulage. The article should be the more convincing when it is realized that Mr. Armstrong, as a member of the General Engineering Staff of the General Electric Company, has been that Company's chief representative in connection with the St. Paul's electrification program since its inception in 1910.—Editor.

Probably no electric railway announcement made in recent years has attracted more attention and provided more instructive reading than the report recently issued by H. E. Byram, President of the Chicago, Milwaukee & St. Paul Railway, covering a detailed analysis of the comparative first cost and cost of operating freight and passenger trains by steam and electricity over 646 miles of track in Montana and Washington. The preparation of this comparison must have been rendered most difficult by the great increase in prices of equipment, material, and labor occurring during the construction and operating period of eight and one-half years covered by the report. The greatest credit is due to the executives of the St. Paul for the impartial and painstaking manner in which they have completed their difficult task, as well as appreciation of the frankness with which they have disclosed the fundamental facts relating to the most extensive railway electrification in the world. Authenticated figures are now made available to the engineering and financial world covering the economic results of this most interesting electric installation.

Summarized briefly the report shows that the operation of this electrical equipment has saved, over the estimated steam-engine operating expenses, the gross sum of $19,233,007 in the 8½ years which have elapsed since electric-locomotive operation was first started. This enormous saving amounts to 123 per cent of the net cost of the electrification chargeable to new capital account after deducting the value of steam engines and facilities released. Moreover, this startling result of electric operation has been made in the face of a gross ton-mile movement which was less in 1924 than in 1916, the first year of electrical operation. Even after deducting interest and depreciation charges against the new electric locomotives and facilities, the economic showing of this electrified property is a most flattering tribute to the railroad executives and bankers who had the courage and vision to apply electricity to a project of this magnitude.

The story of electric locomotive operation over the mountain divisions of the St Paul road furnishes convincing proof of the superior fitness of electric motive power to meet the most exacting operating conditions obtaining on heavy mountain grade divisions. To anyone privileged to ride an electric locomotive under such conditions it is immediately apparent that the steam engine has a rival possessing all the necessary physical qualifications required to haul the heaviest freight and passenger trains over mountain grades at the highest speeds permitted by the limitations of track and draft gear. Unlimited electric power placed at the disposal of the operating engineer has resulted in practically eliminating the dreaded ruling grade of mountain divisions which so seriously restricts train movement with steam engines. While it has therefore become quite generally appreciated that the electric locomotive is physically able to haul any weight of train at any speed on any grade, convincing operating facts have not been available to answer the serious doubts raised in some minds as to the economic return realized upon the capital investment required to effect the change from steam engines to electric locomotives.

The St. Paul report publishes in detail the first cost of the complete electrical installation and compares certain fundamental items of electric and steam operating expense under similar conditions. The results of this comparison surpass the expectations of those who have long awaited its publication. If, as shown, electrification can effect savings in steam operation equal to all additions to new capital account in approximately seven years, with the moderate volume of tonnage hauled on the St. Paul tracks, then the report of that road merits the most careful analysis by those desirous of bettering the physical and economic conditions of our rail transportation system. It is apparent that the spectacular performances of the huge electric locomotives hauling the heaviest trains up grade at speeds never reached with steam engines, and holding them at safe speeds down grade by regenerative electric braking without recourse to air brakes, have a still deeper significance in the economic showing of the electric investment.

It is the purpose of this article to review certain outstanding features of the St. Paul report in the hope of possibly bringing out more forcefully some of the fundamental advantages of the newer type of motive power.

Economic Return on Investment

A word of explanation may be timely in regard to the tabulation(1) which appears on page 4 of the St. Paul report and which shows the volume of traffic in gross ton-miles and savings by electrification. The values given represent net savings after deducting interest and depreciation charges on the electric investment. The relation of gross to net savings may be more clearly brought out as in Table I.

TABLE I

GROSS AND NET SAVINGS FROM ELECTRIFICATION

646 Miles Route

	Harlowton to Avery	Othello to Tacoma
Years operation	8.5	4.7
Net savings	$11,868,247	$531,760
Interest and depreciation written off	4,352,000	2,480,000
Gross savings by electric operation	16,193,247	3,011,760
Gross savings both divisions	$19,233,007	

In eight and one-half years of electric operation in Montana and four and three-fourth years of electric operation over the Cascades, the St. Paul Company estimates that it effected a gross saving of $19,233,007 over what would have been the cost of steam operation with existing equipment during the same periods. This total saving represents a return of 83.6 per cent on the gross first cost of $22,990,254 for the complete electrification of 646 miles, and 123 per cent on the net first cost of $15,625,739 properly chargeable to new capital account after deducting all charge carried against steam engines released for service on other divisions.

Regardless, therefore, of whatever bookkeeping method may be followed in allocating interest and depreciation charges against the net electrical investment, electric operation on the St. Paul Railway is so much lower than the estimated cost of steam-engine operation that the savings realized have more than repaid the net cost of the complete electrification of 646 miles in an average operating period of less than seven years. Moreover, these results were obtained in the face of decreasing ton-miles hauled, which were actually less in 1924 over 646 miles of route than in 1916, the first year of electrification comprising but 438 miles of route. No comment is needed to show that with increased tonnage, which the future may be expected to bring, the economic showing of the St. Paul electrification will fully meet the expectations of the pioneers responsible for its adoption in 1914.

Comparison of Steam and Electric Locomotives

Before electrification, there were in operation over the four mountain grades of the St. Paul Railway a large number of steam engines of the latest types available at that time. This large number of steam engines was replaced by a much smaller number of electric locomotives of larger power. In order to present a more complete basis of comparing steam and electric power in this instance, Table II has been prepared to show not only the number of locomotives of each type but the total weight and weight on drivers as well.

TABLE II

COMPARISON OF STEAM AND ELECTRIC LOCOMOTIVES

646 Miles Route

	Steam	Electric	Ratio Electric to Steam in Per Cent
No. of locomotives	167	59	35.3
Total weight	35,454 tons	16,350 tons	46.0
Weight on drivers	17,727 tons	12,390 tons	70.0
Per cent weight on drivers	50 per cent	76 per cent	

While the total number and total weight of electric locomotives is approximately one-third the number and weight of steam engines they replaced, the total weight on electric drivers is two-thirds that of the steam engines. The weight on drivers affords a truer comparison of the effectiveness of the two types of motive power; and the fact that electric locomotives of much less aggregate weight can haul the same annual volume of tonnage indicates that the electric locomotive is utilized much more efficiently in everyday service than the steam engine. This fact is brought out more clearly in Table III.

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(1) Reproduced as Table I on page 219 of the article by W. D. Bearce in this issue.

TABLE III

MILEAGE RECORD OF STEAM AND ELECTRIC LOCOMOTIVES

646 Miles Route

	Steam	Electric
Freight miles	2,470,254	1,503,179
No. locomotives	132.91[a]	42
Annual miles per loco	18,400	35,800
Passenger miles	1,176,680	969,827
No. locomotives	23.33	13
Annual miles per loco	50,500	74,500
Switching miles	251,737	93,970
No. locomotives	10.08	4
Annual miles per loco	25,200	23,500

(a) Proportioned to handle the same maximum amount of traffic as 42 electric locomotives which handled peak tonnage of 1919 with ease. Hence both steam and electric locomotives are in excess of actual requirements of 1923 traffic.

The freedom of the electric locomotive from boiler and firebox restrictions and the quickness with which it can be turned at terminals is reflected in the greatly increased mileage of electric road engines as compared with steam. The electric locomotive at present manufactured in small numbers is somewhat higher in price than the steam engine which enjoys the material reductions in cost inherent to standardization and quantity production, but the higher priced electric locomotive has proved a much more serviceable machine on the road and its operating record more than makes up for its higher first cost.

The operating records in the St. Paul report indicate a very large reduction in expense and mileage of switching engines. This reduction, as indicated in Table III, is not wholly due to increase in mobility of the electric locomotive but is largely accounted for by the reduction in volume of switching previously required at steam-engine division points since eliminated, to readjust the tonnage of trains to meet the limitations of the smaller capacity steam road engines available. The introduction of electric locomotives of larger power eliminated much of the switching inherent to previous operation with the steam-engine power and facilities in use.

Operating Expenses

Expenses for steam and electric operation on the electrified zones are clearly tabulated in the St. Paul report according to I.C.C. classification of accounts. A somewhat different arrangement of these expenses in more condensed form is given here in Table IV.

TABLE IV

COMPARATIVE OPERATING EXPENSES FOR YEAR 1923

Gross Ton-miles 2,993,507,000

646 Miles Route

	Steam	Electric	PER 1000 GROSS TON-MI.	
			Steam In Cts.	Elec. In Cts.
Maintenance				
Trans. and trolley	....	102,706	...	3.4
Substations	....	30,631	...	1.0
Locomotives	1,335,009	480,236	44.5	16.0
Other items	538,050	398,185	17.9	13.3
Transportation				
Fuel or power	1,790,000	1,228,004	59.8	41.1
Enginemen	836,000	463,945	27.9	15.5
Trainmen	788,000	483,975	26.3	16.2
Enginehouse exp.	285,000	118,895	9.5	3.9
Other items	424,624	321,363	14.1	10.7
	$5,996,673	$3,627,940	200.0	121.0
Electric saving		$2,368,733		79.0

Gross return year 1923 on Gross Expenditure

$$\frac{2{,}368{,}733}{22{,}990{,}254} = 10.3 \text{ per cent.}$$

Gross return year 1923 on Net Expenditure (addition to capital account)

$$\frac{2{,}368{,}733}{15{,}625{,}739} = 15.2 \text{ per cent.}$$

Engine Maintenance

Commenting more in detail upon the several items of operating expense entering into this comparison between steam and electricity it is instructive to group together first cost and maintenance expense as in Table V.

TABLE V

FIRST COST AND MAINTENANCE EXPENSE

646 Miles Route

	Total First Cost	PER MILE ROUTE		Percentage of First Cost
		First Cost	Maint. Cost	
Transmission and trolley[a]	$8,404,002	$13,000	$158.00	1.21
Substations	4,324,282	6,680	47.30	.70
Locomotives	8,069,574	12,500	743.00	5.95
Misc.[b]	2,192,396	3,390		
	$22,990,254	$35,570		

(a) Does not include extraordinary expenses such as renewing anchors, stubbing poles, etc.

(b) Miscellaneous expense largely made up of interest during construction and signal system.

This table brings out the instructive information that while transmission line, trolley construction, and substations constitute nearly 56 per cent of the total gross expenditure for electrification, they are being maintained in respect to running repairs at an annual expense of only one per cent of their first cost of installation. It will be interesting to learn how much additional expense will be required for replacement of poles, etc., occurring at long periodic intervals.

The electric locomotives constituting 35 per cent of the total gross expenditure, cost approximately six per cent of their purchase price for upkeep each year. This may seem a disproportionate maintenance charge, but in fact it represents the inescapable penalty of maintaining mobile equipment, like locomotives, subject to all the vicissitudes of running on rails, compared to the much smaller expense attached to operating stationary equipment with its more conservative design and lesser hazard. The penalty imposed upon maintenance of mobile equipment of another type is brought out in a more startling manner by analysis of steam-engine upkeep as a percentage of its first cost, as given in Table VI.

TABLE VI

FIRST COST AND MAINTENANCE EXPENSE OF STEAM AND ELECTRIC LOCOMOTIVES

646 Miles Route

	Steam	Electric
Total number of locomotives	167	59
First cost	$5,615,505	$8,069,574
Annual maintenance expense	1,335,009	480,236
Percentage of first cost	25.3	5.95

As these investments in steam and electric locomotives are assumed to be comparable for the same service rendered, the pertinent conclusion is drawn that under St. Paul operating conditions it costs 25 per cent of the purchase price of steam engines to maintain them in running condition each year compared to six per cent for electric locomotives. The operation of the latter is saving the St. Paul road each year $854,773, or approximately two-thirds of the engine maintenance expense that would have been incurred had steam-engine operation continued in 1923. This saving in locomotive maintenance expense alone is sufficient to pay the interest charge of 5½ per cent on additions to capital account incurred by electrification on the St. Paul, and the achievement is all the more noteworthy when it is considered that the electric locomotives are comparatively newcomers in the traction field and are competing with steam-engine construction, operation, and experience that has been slowly perfected during a century of development in railroading. Neither the electric locomotives nor the steam engines they replaced on the St. Paul railway fully represent modern equipment of either type, embodying improvements made during the past 10 years. Many additions to steam engines have been made and include mechanical stokers, superheaters, feed-water heaters, booster on trailing engine or tender truck, and other devices installed to increase their output and improve their fuel economy. In these respects they have been successful but the addition of these devices has also contributed largely to increased cost of maintaining the more complicated engines so equipped.

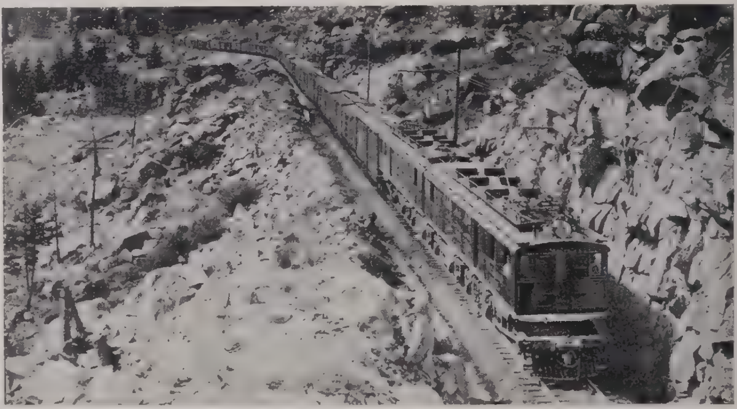

Fig. 1. Electrically Hauled Freight Train Descending a 2 Per Cent Grade East of the Rockies. The train is held entirely by regenerative electric braking

Electrical equipment has also been improved, as it must be remembered that the St. Paul 3000-volt direct-current locomotives were the first of their type, and in 1914 were designed new in every respect for a service which in magnitude and severity surpassed anything attempted up to that time.

Furthermore, actual operating experience with the new type of power on such an extensive scale and under similar conditions did not exist, whereas the efficient handling of the steam equipment had been the result of many years' development. Much credit for the low maintenance expense of the electric operation is due to the facility with which the operating and maintenance personnel of the railway developed the effective use of the new equipment and facilities, as well as to the engineers in charge of the electrification work and to those of the General Electric Company, who designed and furnished the locomotives and substation apparatus of the initial installation.

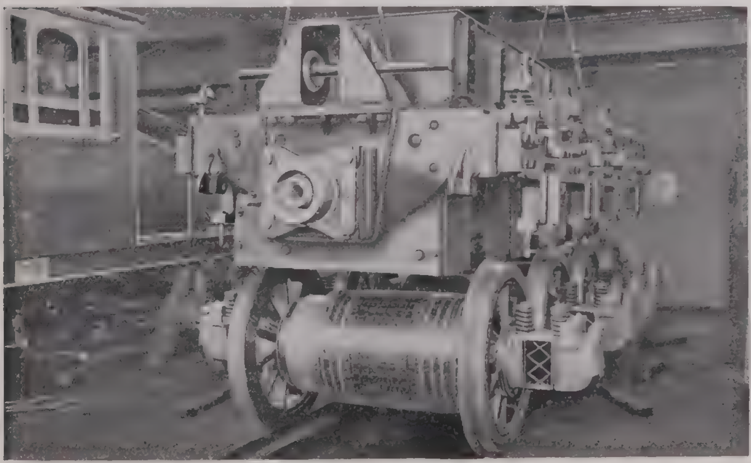

Fig. 2. Assembling Motor Truck for a Gearless Electric Locomotive at the Erie Works. Each locomotive carries four of these driving units

If the steam engine could be divorced from its boiler and firebox and reduced to the simplicity of cylinders, pistons, and running gear comprising its motive power only, it would undoubtedly prove fully as reliable and cheap to maintain as the electric locomotive. The burden of providing for and carrying about a steam generating plant is a serious disadvantage to steam-engine design and operation, and is the penalty paid for its independent mobility over any track, a feature which the electric locomotive lacks.

The cost of upkeep of the complete electric distribution system, including substations, is surprisingly low. Adding the cost of maintaining the transmission line, trolley construction, and substations to the electric locomotive upkeep figures given, the total annual cost of maintaining the complete electric installation (costing $22,990,254 to install) is less than half the sum required each year for upkeep of the steam engines alone previously assigned to the same divisions. This convincing proof of reliability and low maintenance charges of electric equipment presented in the St. Paul report is one of its outstanding features and is a strong argument for the stability of capital investment in such property.

Electric Power and Engine Fuel

Deduced from basic figures given in the report, power was purchased by the St. Paul Railway for 0.75 cent per kw-hr., Harlowton to Avery, and 0.83 cent per kw-hr., Othello to Tacoma, both figures being favorable to electric operation. It is interesting to note in this connection that the load-factor of the Montana Division approximates 50 per cent.

The foregoing electric power figures(2) do not include an annual operating expense of $141,936 for the 22 substations appearing under items "train and switching power produced"(3) and amounting to approximately 13 per cent of the total power expense for the two electric divisions. This substation expense is only to a comparatively small extent affected by tonnage moved, as it includes, mainly, the wages of operators and full shifts are being worked in nearly all the stations.

Present substation capacity installed is ample to supply adequate power for a material increase over the present annual tonnage now hauled over the 646 miles of electric divisions.

It is instructive to deduce, from Table VII, the coal burned on steam engines equivalent to the same service performed by one kilowatt-hour of electric power purchased.

TABLE VII

COMPARISON OF FUEL AND ELECTRIC POWER FOR FREIGHT MOVEMENT HARLOWTON-AVERY

Tons coal	132,900 tons
Oil equivalent 3 bbl. = 1 ton coal	98,446 tons
Equivalent coal total	231,346 tons
Lb. coal at 2000 lb.	462,692,000 lb.
Kw-hr. freight	75,850,552 kw-hr.
Lb. coal per kw-hr.	6.10 lb.

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(2) I.C.C. account No. 384 and No. 396.
(3) I.C.C. account No. 383 and No. 395.

Improvements have been made in both steam engine, electric locomotive, and power distribution economy during the past 10 years, but the St. Paul figures indicate that fully six lb. of coal (11,500 B.t.u's.) may be burned on a steam engine in road service to haul the same gross tonnage handled by electric locomotives for one kilowatt-hour purchased at the high-tension transmission line. As the great bulk of power for any general electrification of railways must be produced in coal-fired steam stations, the above comparison gives point to the statement that approximately two-thirds of the fuel now burned on our railways, and constituting 17 per cent of all coal mined in this country, could be saved by electrification of all lines.

Train Crews

A comparison of accounts for enginemen and trainmen show a material saving effected by electric-locomotive operation. This is in large part due to the substitution of heavy for light engine power, and the saving would have been nearly as great with steam operation following the same increase in weight of individual engine power. In this respect, credit is due electric locomotives on account of fewer engine failures and the higher speed at which they can deliver full tractive power on ruling grades, as these contribute materially to the elimination of overtime expense common to operation of steam engines of limited power over a broken profile. Former steam-engine crews readily acquired the knowledge and skill necessary to operate electric locomotives and the change from steam to electricity was made with slight change in operating personnel in the electrified zones.

Enginehouse expense is greatly reduced with electric operation due largely to discontinuance of two division points and the elimination of the steam boiler and fire-box which necessitate boiler washing, cleaning fires, dumping ashes, as well as the many minor repairs made on steam engines and charged to enginehouse expense. The St. Paul electric locomotives are double-ended, require no turntable, and are being operated in continuous service for 5000 miles or more between inspections. Operating figures given show the large saving resulting from the elimination of the steam boiler and fire-box which are responsible for so much of the expense and delay in turning steam engines at terminals.

General Conclusions

The report of Mr Byram leaves no doubt that the St. Paul electrification has been an economic success and shows a surprisingly large return upon capital additions considering that the St. Paul tonnage has fallen off rather than increased as there was every reason to expect.

It is difficult to apply this comparison to other roads as the St. Paul operating conditions are peculiar to itself. Certain fundamental facts, however, appear to be clearly established which have general application to steam and electric locomotive operation as such and these may be briefly summarized as follows:

(1) Electric locomotives have proved able to haul the heaviest freight and passenger trains over severe mountain grades under all weather conditions in a reliable and safe operation.

(2) Electric operation has saved the St. Paul railway large sums each year which would otherwise have been required to continue steam operation.

(3) The estimate of total gross savings effected by the electric operation of the Eastern Division for 8.5 years and the Western Division for 4.75 years amounts to \$19,233,007, or a return of 123 per cent on the net cost of electrification of \$15,625,739.

(4) The fixed charges on power transmission and distribution are high per 1000 ton-miles moved on account of the small annual volume of traffic.

(5) The maintenance charges on the power transmission and distribution systems have thus far been surprisingly low, amounting to but one per cent of the first cost as annual expenditure.

(6) The maintenance of electric locomotives is but one-third of that estimated for steam engines hauling the same tonnage, this annual saving of \$854,773 being a sum sufficient in itself to pay interest charges upon the net cost of the complete electrification.

(7) The cost of electric power shows a saving of \$560,000 per year over the estimated steam-engine fuel, due largely to the favorable water-power conditions obtaining in the Northwest.

(8) The estimated saving of \$672,000 per year in train-crew expense is due largely to the substitution of heavier for light engine power, and is not entirely an inherent saving due to electrification.

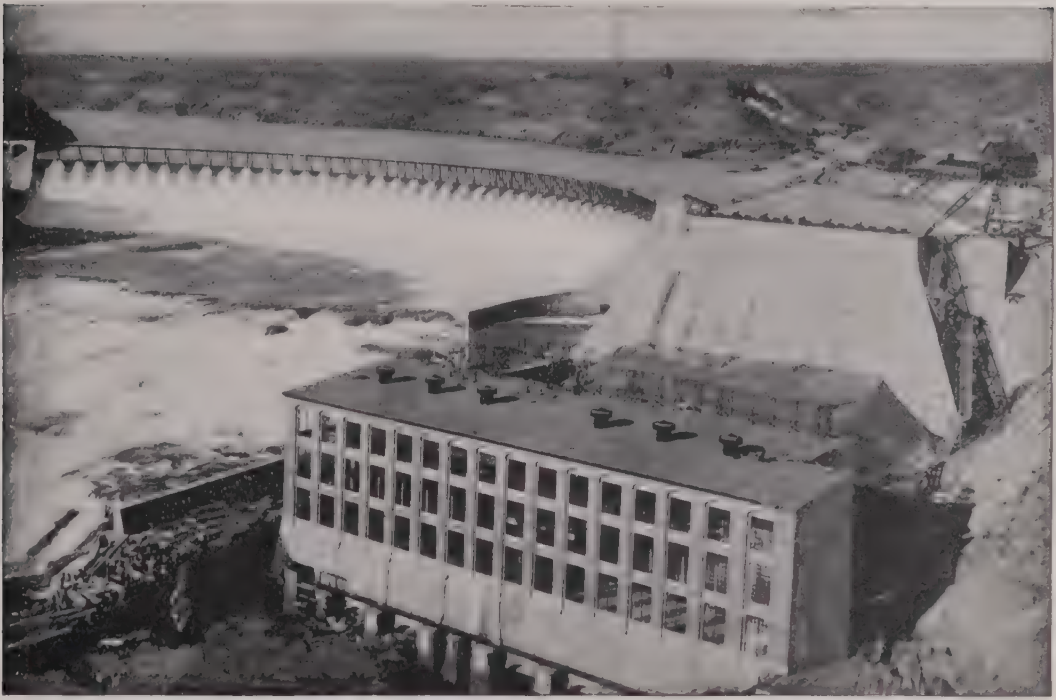


Fig. 3. The 60,000-kw. Generating Plant of the Montana Power Company on the Missouri River at Great Falls, Montana. This plant was built principally to supply power for the St Paul electrification

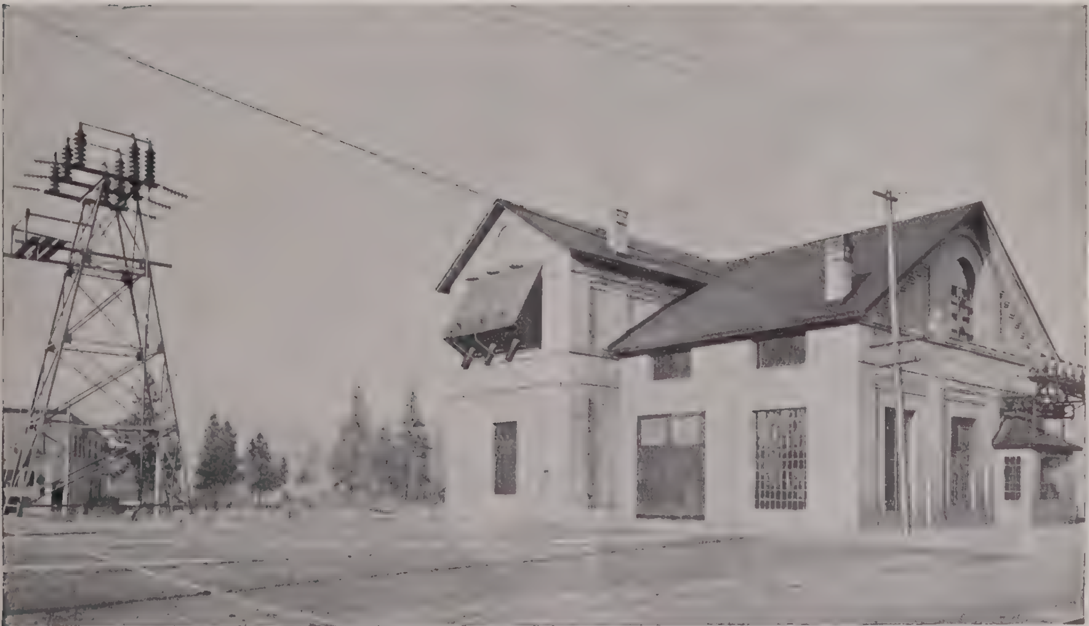


Fig. 4. Typical Coast Division Railway Substation, built with gable roof to withstand the heavy snows encountered in the Cascade Mountains. The snowfall during the season sometimes exceeds 100 ft.

(9) Other savings amounting to approximately $409,231 per year are made up of several items, chief of which is a large reduction in the enginehouse expense estimated for steam operation.

(10) A study of the comparative cost of steam and electric operation indicates a much larger saving by electrification would result with greater tonnage moved.

The report is not a comparison of modern steam and electric locomotives comprising all the improvements made in the last ten years elapsing since the initial St. Paul installation was made. It compares the steam engines of 1914 with the electric locomotives designed in that year and in 1916. The outstanding economic feature o the report is the very large reduction shown in the expense of engine maintenance and this advantage of electric over steam locomotives appears to be fundamental as further evidenced by operating records of other railways. Additions to steam engines since made and now considered essential to modern engine equipment are effective in increasing output and fuel economy but do not contribute to any reduction in cost of upkeep. It is a serious economic matter to provide for a maintenance charge on steam motive power which equals its first cost in four years.

Electric locomotive improvements on the contrary have been made to still further increase its reliability. With the modern steam engine becoming more complicated and costly and the electric locomotive being designed for greater simplicity and reliability, there is sound reason to expect a much lower cost of upkeep as a fundamental advantage inherent to future electric motive power.

The first cost of steam and electric locomotives are not widely different in the report, especially for freight service, and it may be considered a standoff in new electrifications if the future brings about anything approaching quantity production and uniform design of the latter. Additions to capital account incurred by electrification, therefore, appears largely in power transmission and distribution expense. The annual cost of maintaining this construction is very low especially if the annual volume of traffic handled is large. The St. Paul power transmission and distribution system is adequate to supply power for a material increase in the number of trains now hauled, thus indicating how comparatively unimportant the operating and fixed expenses for this construction would be on other electrified roads more happily favored with respect to greater volume of traffic.

The fundamental reason for considering any railroad electrification centers in the relative performance of the steam and electric locomotive. Its adoption may relate to track congestion, grade revision, tunnel operation, smoke abatement, bad water conditions, heavier trains, higher speeds, or other conditions reflecting the limitations of the steam engine. In nearly every instance, however, the electric locomotive is called upon to do something not possible with steam engines. To these reasons influencing the adoption of electrification, the St. Paul report contributes such convincing operating facts as to warrant the belief that economic necessity alone may hasten the replacement of the steam engine under certain favorable conditions.

Electrification of our railways may well point a way to solve the difficult problem of meeting the desires of railway investors and employees for increased return and at the same time satisfy the demands of the general public for lower transportation rates and improved facilities.

Joint Operation of Steam and Electric Trains Over the Dallas-Denton Division, Texas

By B. F. Cooke

Superintendent of Power, Texas Interurban Railway, Dallas, Texas

The exceptional versatility of electric power application is well exemplified in this case where the interurban advantages of electric motive power have led to its adoption in connection with branch-line steam service and *over the same tracks*. Furthermore, electrification is not only possible under these conditions but preserves the well-known operating advantages of "straight" interurban electrification. The electrical equipment, including passenger and express cars served by supervisory controlled automatic substations, is virtually an independent system operated in schedule harmony with the steam system by a dispatcher common to both. The physical characteristics of the trackage, the method of electric power supply and control, and the features of dispatching are explained in the following article by the Superintendent of Power of the Interurban Company.—Editor.

On May 15, 1922, the Missouri-Kansas-Texas Railroad Company and the Texas Interurban Railway entered into a contract, for a term of 50 years, under which the Missouri-Kansas-Texas Railroad would be electrified between Dallas and Denton, Texas, and used jointly by the Railroad Company's steam trains and the Interurban Company's electric cars.

The electrification was begun in March, 1924, and completed October 1, 1924, at which time interurban service was opened.

Track Laying and Trestling

The distance between Dallas and Denton is 38.66 miles, of which 33.38 miles are Missouri-Kansas-Texas Railroad Company tracks. From the Dallas Interurban Station to the city limits the Interurban uses the Dallas Railway Company (city lines) tracks. The Interurban Company built 1.5 miles of its own track between the city limits of Dallas and a point near the railroad yard limit where its tracks join those of the Railroad Company. The Interurban Company also built its own track between the Denton Interurban Station, which is located in the business district, and a point near the railroad yard limit at Denton. Several additional spur tracks were built to accommodate meeting trains between Dallas and Denton. Seventy-pound rails were used on all new work, the Railroad Company's tracks being of 66-lb. rails.

The Railroad Company supervises and maintains all property used jointly by the two companies, for which it is reimbursed monthly by the Interurban Company. The Interurban Company cares for the maintenance and supervision of all property used solely for the operation of electric cars.

Two trestles were built by the Interurban Company just beyond the city limits of Dallas. One is of pile construction and is approximately 400 ft. long, and was built to span Cedar Springs Creek and to furnish an under-pass for a proposed highway. The other is of steel construction supported on concrete pilasters, is approximately a quarter of a mile long, spans a small creek, and furnishes an under-pass for a county road and the St. Louis and Southwestern Railroad. The trestle work ascends to the over-pass on a 5 per cent grade with a 20 deg. reverse curve, both of which were necessitated by the existing street and railroad grades. This latter structure was built at a cost of approximately $45,000.

Power and Transmission

Power for the line is furnished by four substations, one of which is manually operated and is located one mile from Dallas. The other three are automatic substations and are located 13.5, 24.5, and 36.5 miles from Dallas, leaving a two-mile stub feed on the Denton end. The manually operated station is owned and maintained by the Dallas Power and Light Company (the local Power Company), and furnishes power for the operation of city cars as well as the interurban cars. This station contains one 1000-kw., 600-volt direct current, motor-generator set, and has space for two additional machines of the same size.

The three automatic substations are owned and maintained by the Interurban Company, however. Power for them is furnished by the Texas Power and Light Company's 60,000-volt high-tension line serving this territory. The high-tension structures are of the outdoor type and serve small towns in their vicinity as well as the railway substations. The converter and switching equipment are housed in a brick structure 20 by 20 ft. inside dimensions. Louvers in the walls near the floor and vents in the roof provide adequate ventilation. The louvers and vents can be opened or closed to regulate the room temperature. An oil-cooled, three-phase/six-phase, 300-kv-a. transformer, Y-connected primary and diametrical secondary, is used to step the voltage down to 445 volts and a 300-kw. synchronous converter is used to convert it into 600 volts direct current. In addition to the transformer and converter, each station is equipped with alternating-current and direct-current arresters for lightning protection, one 5-kv-a. control power transformer (445 to 220-110 volts), which is also used for station lighting, and automatic switching equipment for performing the starting and stopping operations ordinarily done by the station operator in manually operated stations. Various protective devices safeguard the station against damage by abnormal conditions or irregularities occurring on the system or within the station. One of the most noteworthy recent developments in automatic equipment is the motor-operated time-delay relay. This relay is a vast improvement over the oil dash-pot relay, in as much as it affords a more definite and wider range of time settings.

Each station has a ¾-in. galvanized pipe running underground from inside the station to a post near the track where it is brought up in a convenient place and a short hose attached for connection with the compressed air tanks on the line car. On its inspection trips the line car stops at each station, "blowing out" the machinery and other equipment weekly, and painting the converter winding with an "air brush" yearly.

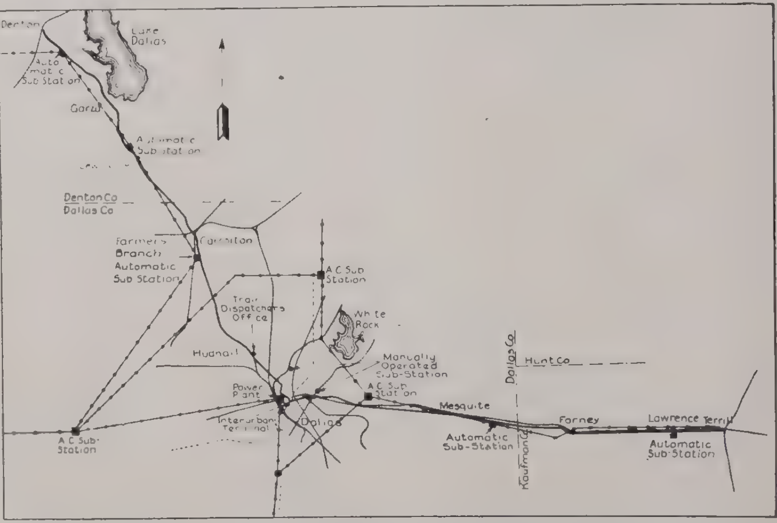


Fig. 1. Map of the Dallas-Denton Division, Showing Also the Location of the Automatic Substations and Power Lines

The negative return between the rails and the station consists of a 1,000,000 cir. mil bare copper stranded cable run underground in a two-inch galvanized pipe. A brass wiping cap is screwed on at each end of the pipe and a joint wiped to the copper cable. Thus the galvanized pipe serves as a conductor as well as protecting the cable from mechanical injury and deterioration. The pipe joints are bonded to prevent electrolysis at these points. One end of the copper conductor is connected direct to the converter and the other end is soldered to five 0000 cross bonds between the rails. The rails are bonded with 0000 ribbon brazed bonds and 0000 cross bonds are used at every "feed-in" tap to tie the two rails together.

The positive feeder between the station and trolley wire feeder consists of a 750,000-cir. mil copper conductor insulated for 3000 volts and lead covered. This cable is in a 2-in. galvanized conduit. The conduit was run from the station under a paved highway and up a pole to a pot head just below the trolley wire feeder. The iron conduit is considered as adequate protection for the station against lightning. However, a "panel-board arrester" was installed on the pole to protect the cable from lightning. The 3000-volt insulation was used as an extra precautionary measure. The usual precautions were taken to protect both cable and conduit from electrolysis.

The overhead system is of the catenary type with five-point suspension supported by single 40-ft. poles set 9 ft. below the top of the rail and spaced approximately 150-ft., except along the Interurban Company's tracks near Dallas and near Denton where direct suspension is used with 100-ft. pole spacing. The actual spacing, however, is governed by existing conditions. The poles are of Southern long-leaf yellow pine treated by the "Rueping" process. All poles are back-guyed with "never-creep" anchors. Storm guys are placed every half mile and at each end of curves. The trolley wire is 0000 grooved copper supported by $\frac{7}{16}$-in. double-galvanized stranded steel cable. A 300,000-cir. mil feeder, mounted on steel brackets, parallels the trolley wire the entire length of the line with six feed-in taps to the mile. Lightning arresters were placed at every feed-in tap. Corrugated cast-iron plates were set under the bases of the poles and a ¾-in.

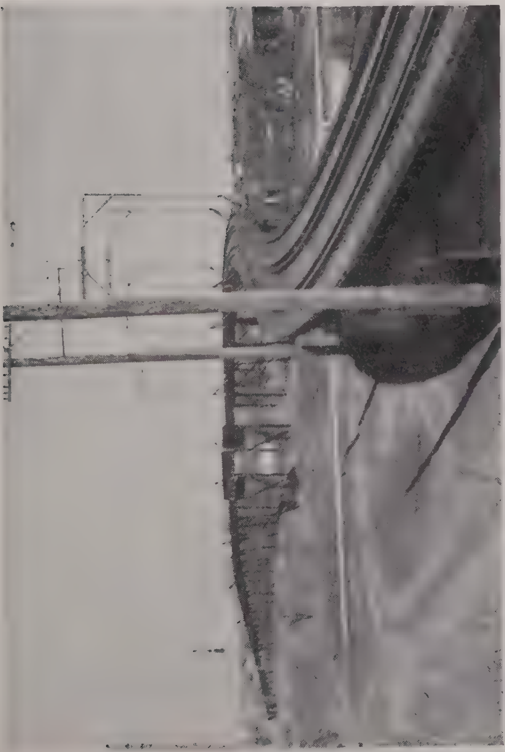


Fig. 2. Steel Railway Trestle with a 20-deg. Reverse Curve on a 5 Per Cent Slope

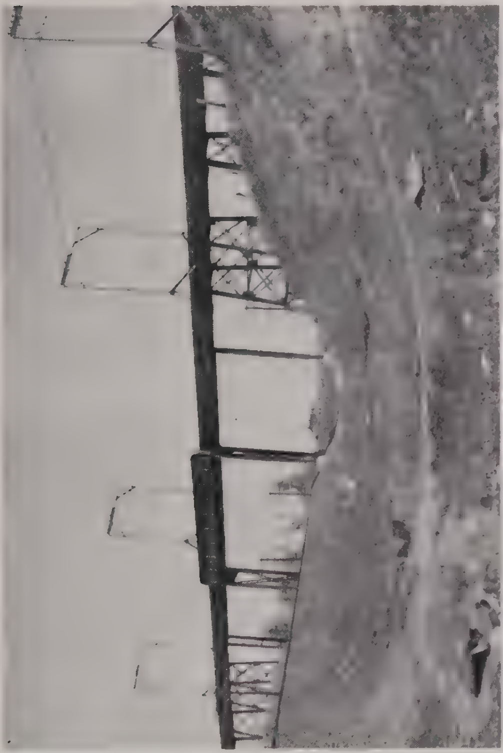


Fig. 3. Side View of a Straight Portion of the Steel Trestle Shown in Fig. 2

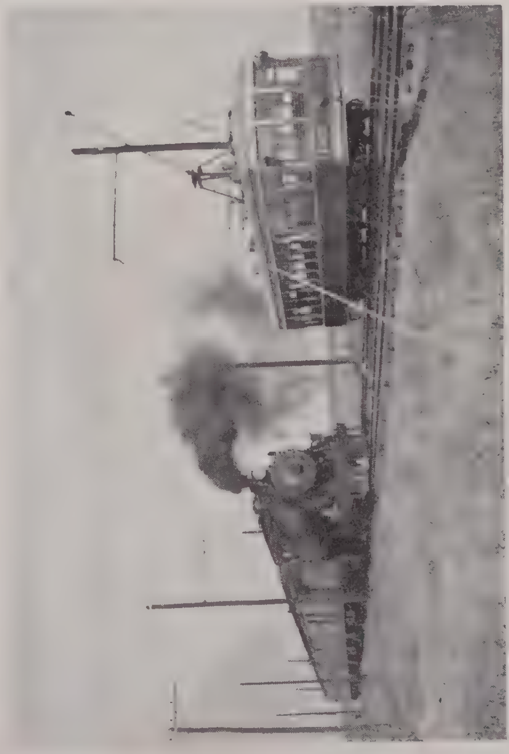


Fig. 4. Steam Train and Electric Car Operating Over the Same Track. The electric car takes the siding while the steam train passes

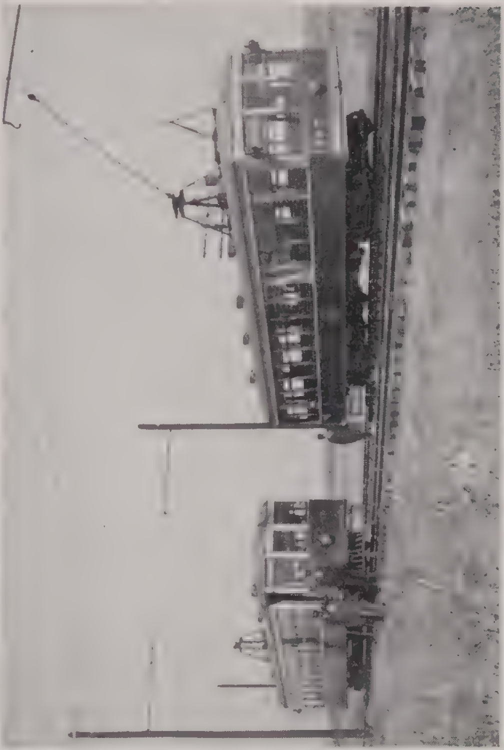


Fig. 5. Electric Cars in Use on the Texas Interurban Railway. These cars are of the one-man type and will seat 52 passengers

galvanized pipe, screwed into the plate and extending six inches above the ground, was used for the lightning arrester grounds. A brass cap screwed on the end of the pipe afforded a convenient means of connecting the ground wire. A tap from the ground wire was also soldered to the rail cross bonds.

Telephone and Supervisory Control System

The telephone system consists of two metallic-return telephone circuits extending from Denton to Terrell, via Dallas. One of these circuits is known as the "Dispatcher's line" and is normally used for dispatching trains over both the Denton and Terrell Divisions. The dispatcher "listens in" on this line at all times under normal conditions. (The Terrell Division is owned by the Interurban Company and is 31.5 miles in length. Electric cars only are operated over this Division.) The other circuit is known as the "Commercial line" and is normally used for commercial purposes and for the supervisory control of the automatic substations on the Denton Division.

A third line wire is used with this circuit in connection with the supervisory control system. Selective apparatus is used on both the commercial and dispatcher's circuits. Each line is separately equipped with key cabinet and keys, apparatus cabinet, and storage battery. The commercial line also serves as an emergency dispatcher's line. The telephones at the various booths and way-stations along the line are equipped with jack-boxes and plugs to permit plugging the instruments in on either line.

The train dispatcher operates the automatic substations by means of the supervisory control and also serves as a telephone switchboard operator on the commercial line. For instance: If Denton wanted to talk to Terrell, Denton would plug in on the dispatcher's line and ask the dispatcher to ring Terrell. Denton would then plug back on the commercial line for the conversation, the dispatcher having rung Terrell on the commercial line. Every way-station is equipped with two selectors, one for each line.

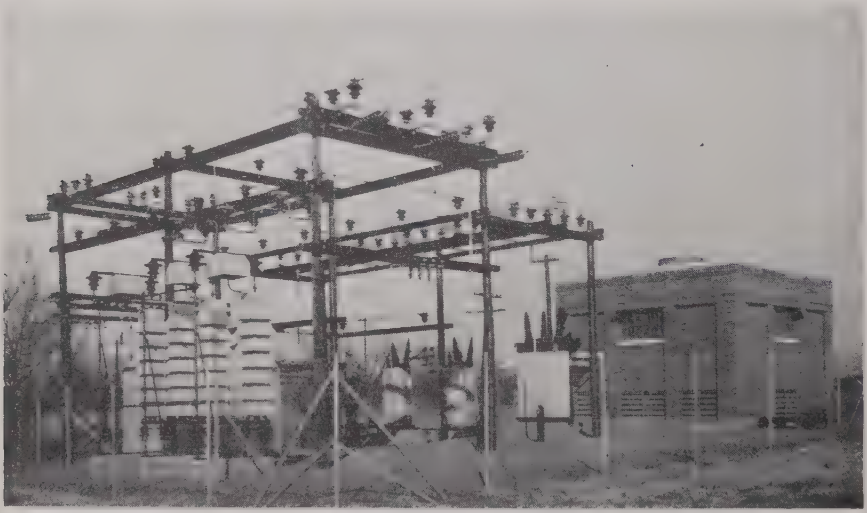


Fig. 6. Farmers Branch Automatic Substation Equipped with One 300-kw., 600-volt Synchronous Converter

The use of the supervisory control for operating the automatic substations has several advantages over straight automatic operation. Three selector keys and two signal lights, one red and the other green, are used with each station. One key is for starting, one for stopping, and one for turning the station over for automatic operation. The signal lights indicate whether a station is running or shut down; the red light burning when the station is running and the green light burning when the station is shut down. A bell in the office rings when a change in the lights takes place, to inform the dispatcher that a station is either starting or stopping. These signal indications are a great help in preventing delays in train service due to lack of power. In case a station shuts down, due to the functioning of one of its protective devices or to high-tension line trouble, the dispatcher is informed immediately and can usually get a trouble man on the job before delays result. Without the signals he would not know of the trouble until the trains were delayed and then he might not know which station was out or whether high-tension line trouble was the cause. With the signal lights the dispatcher knows when high-tension line trouble occurs, by all the stations shutting down at the same time, and so can notify the Texas Power and Light Company. Otherwise he would naturally call an Interurban Company trouble man out unnecessarily.

The advantage of starting and stopping the stations with selector keys results from operating conditions peculiar to the system. Under automatic operation the cars will hold a station on the line continuously through the day, operating at an uneconomical load factor. This is due to the frequency of stops along the line and the heavy flow of current while the car is accelerating after having made a stop. The time-delay stopping relay will reset due to the rush of current when the car starts, and before the relay has "timed out" another stop is made, resetting it again. Thus the station is held on the line continuously when in reality it is only needed a part of the time. Shortening the time setting so the station will shut down, causes it to shut down when a car makes a stop or is waiting on a siding. This frequent starting and stopping is more detrimental to the station equipment than continuous running.

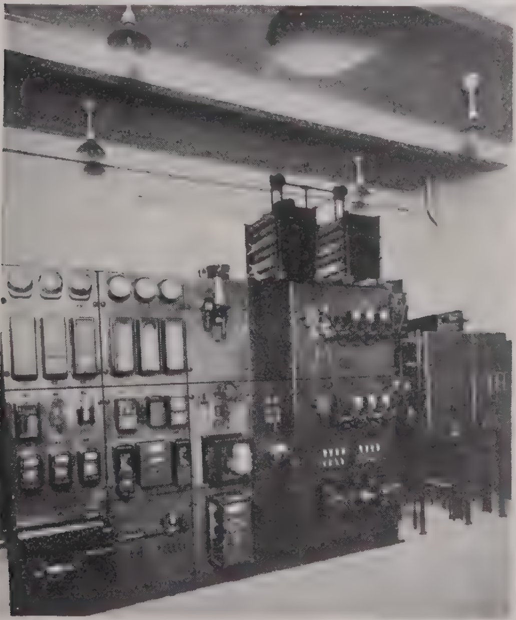


Fig. 7. Control Panels, Starting and Running Panels, and Load-limiting resistance for 300-kw., 600-volt Synchronous Converter in Substation Shown in Fig. 6

The train dispatcher knows the approximate location of all trains on the system at all times, each agent reporting to him when a train passes his station. Being familiar with the location of trains, the dispatcher knows where there is demand for power and operates the substation accordingly. A regular substation operating schedule has been prepared from the train schedule, but this of course cannot be used when trains are late. However, late trains are a rare occurrence on this system. Ordinarily the dispatcher starts or stops the stations at certain predetermined times of the day. In case there are delays and the trains get off schedule, he uses his judgment and starts or stops each station according to the demand for power, or he can lock all the stations in and keep them running until the trains get on time.

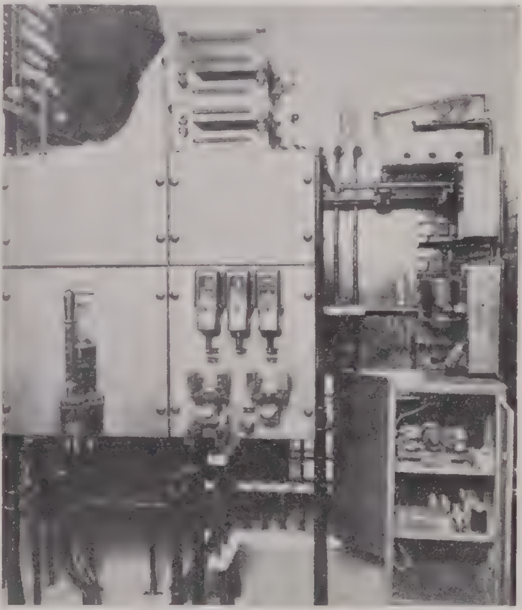


Fig. 8. Selector Type Supervisory Control Cabinet and Auxiliary Panel in Substation Shown in Fig. 6

The automatic starting relays (contact-making voltmeter) in the substations are set to start the station in case the trolley voltage falls to a certain minimum value; and the stopping relay to shut down the station under conditions of prolonged underload, regardless of the supervisory control system. Therefore, the stations will function automatically in case the dispatcher fails to operate them, thus eliminating the only objectionable feature, that of the "human element."

The application of supervisory control to this system will save more than a thousand dollars a year in conversion losses in addition to the resultant saving in maintenance and depreciation. Another desirable feature of this installation is that, by adding another key to the key cabinet and a selector with auxiliary equipment, almost any kind of signal at any point on the line can be operated from the dispatcher's office. At present there are no such signals in use, but in case future developments demand them, they can be installed at very little expense.

Train Operation

The electric rolling stock for this line consists of six light-weight one-man passenger cars and one express car. These are of the same type as those on the Terrell line and can be used on either line. The Terrell line has five passenger and two express cars, making a total of eleven passenger and three express cars for the two lines. Seven passenger cars and two express cars are required for schedule operation on the two lines. Four passenger cars are used on the Denton Division and three on the Terrell. One express car is used on each Division. The other express and four passenger cars are maintained for emergency use. The passenger cars weigh approximately 32,000 lb. and are 45 ft. in length over all. They seat 52 passengers and have a standing capacity of approximately 100. Each car is equipped with four 35-h.p. motors (GE 265-A), one controller (K-35), 26-in. wheels, Brill trucks (77-EI), a 15-cu. ft. air compressor (CP-27), and straight air brakes with auxiliary valve for opening and closing the sliding door.

The fare box is mounted near the entrance to the car and the passengers pay on entering. The top compartment of this box is glass enclosed to permit the car operator to read the ticket or count the money each passenger deposits. He then presses a lever allowing the ticket or money to fall into a lower metal compartment, emptying the top compartment for the next passenger's deposit. A "Destination check" having a number printed in large figures on both sides is handed to each passenger as he drops his fare in the box. This number corresponds to the number of the particular stop to which the passenger has paid his fare. The passenger deposits this check in the box upon leaving the car, so that the operator can determine from the number on the check whether the passenger is getting off at the stop to which he paid his fare.

Hourly interurban passenger service is provided each way from 5:00 a.m. until 11:00 p.m. The Electric Express and Baggage Company operates two express cars each way daily. The Missouri-Kansas-Texas Railroad Company operates four passenger trains and two freight trains daily. The schedule running time between the city limits of Dallas and Denton averages 28 m.p.h. Eighteen minutes is required for the 3.5-mile run from the Interurban Station at Dallas to the city limits. The running time from Dallas Interurban Station to Denton Interurban Station (38.5 miles) is 1 hr. 40 min.

All trains operate under the Railroad Company's standard rules so far as they are applicable to the particular train. In addition to the standard rules, special rules governing the joint operation of steam and electric trains were drafted by the officials of the two companies. Passenger trains, both steam and electric, are "first class." Electric express cars are "second class" and steam freight trains are "third class."

The Railroad Company dispatchers control the movement of all trains over the system. The dispatcher's office is located at the junction of the Railroad Company and Interurban Company tracks just beyond the city limits of Dallas. These same dispatchers also dispatch trains over the Terrell Division. At the junction of the Railroad and Interurban Company tracks near Dallas and near Denton the switches are normally lined for Interurban operation. The dispatcher operates the switch for steam trains at the junction near Dallas, but one of the train crew has to operate the switch near Denton, thus necessitating the stopping of steam trains at this junction.

Where steam passenger trains and interurban cars meet, the train occupies the main line while the interurban car takes the siding, the car being able to get in and out of a siding more rapidly than a steam train. The cars generally clear the main line in time to allow the steam trains to pass on without making a stop. The trains, however, are required to approach meeting points under control. Each interurban car carries a negro porter who attends to flagging and assists passengers with their baggage. So far, joint operation of the different type trains over the same tracks has been successful beyond all expectations.

The Mill-type Magnetic-time Control System

By J. D. Wright

Industrial Engineering Department, General Electric Company

The most serious difficulty confronting the designer of electric motor equipment is the great divergence between starting and running conditions. Factors of momentum, acceleration, and possible overload at starting must be taken care of in such a manner as not to compromise the running characteristics more than necessary. For this purpose, there has been developed a great variety of controllers ranging from simple rheostatic apparatus to the more elaborate relay equipment. The special starting problems of steel mill auxiliary motors have recently been met more satisfactorily by the adoption of a new type of control mechanism. Mr. Wright's article describes this system of control, and explains why the development of it was necessary.—Editor.

The one most essential requirement of an auxiliary drive in a steel mill is that it shall in no way delay the operation of the mill of which it is a part. When the operator moves the master-switch handle to a running position, the motor must start or, failing to start after exerting the maximum possible starting torque within its capacity, it must be disconnected from the line. The motor must and will do its utmost, but it can do so without injury only when governed by the proper type of control equipment. It is the control that must make the motor go about its work with only normal effort or, in case of need, exert the greatest power of which it is capable. The control must also provide that the motor shall not be overtaxed but, having once done its utmost, shall be relieved of further effort which could only result in damage.

For many years controllers providing current-limit acceleration have been extensively used. Where the load conditions are practically constant, this system may be ideally applied. However, if the loads are variable, the current-limit control must be adjusted to meet the worst condition. This adjustment once made is rarely changed, with the result that the motor and control are forced to handle all loads with the same effort as is required for the maximum. In steel-mill service the heaviest auxiliary motor loads frequently occur when a cold mill is first being put into operation. It does not take long to get the mill "limbered up" and the extreme load conditions are then largely eliminated.

Steel-mill engineers, realizing the vital necessity of maintaining continuity of operation, are always striving for greater simplicity of control. They are often willing to give up some of the advantages of more complicated systems for the greater simplicity of less theoretically perfect systems. It is for that reason that there exists a growing demand for a good time-limit control.

It is the object of this article to describe an equipment developed primarily to meet the demands of steel-mill electrical engineers for a simple, rugged, and reliable magnetic controller which will provide definite time control of the motor acceleration. Time-limit controls are not new. It is the fact that the timing is obtained simply and reliably by a magnetic effect that makes this control system unique. It has been called the "MT" system, not only because of its "Magnetic Time" features, but also because the devices used to make up the controller have been particularly designed to give long life under the severe operating conditions encountered in steel mills, and have proved themselves worthy of being called "Mill Type."

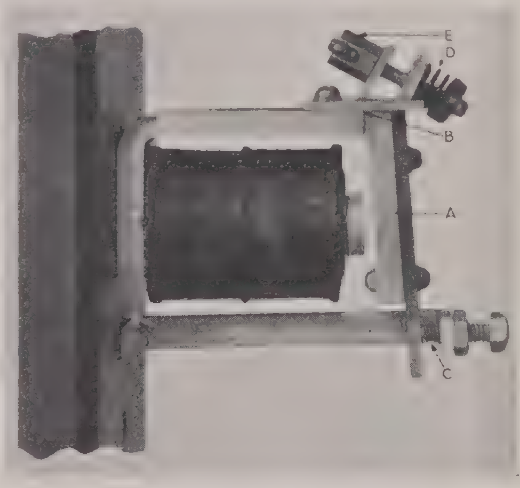


Fig. 1. Definite Time Delay Accelerating Relay

The timing of the accelerating contactors is obtained by the use of the relay shown in Fig. 1. Its armature *A* has a bearing of the knife-edge type at *B*. The contacts *C*, which are connected in the coil circuit of an accelerating contactor, are normally closed.

After the relay armature has been picked up, its coil is short-circuited by a contactor as will be described later. Due to the self inductance of the short-circuited coil, a definite time is required for the flux to decrease to a point sufficient to allow the armature to release, and it is thus that time-limit acceleration is obtained. An adjustment of the pressure of the calibrating spring *D*. by turning the nut *E*, permits of varying the time from 0.4 to 1 second. Each accelerating contactor is provided with one of these timing relays. In view of the fact that most steel-mill auxiliary motors must be accelerated in a maximum of 2 or 3 seconds with controllers having two or three accelerating contactors, it is evident that the maximum relay timing is entirely ample.

The time characteristic of the relay is practically unaffected by the usual voltage variations encountered in a steel mill, and a change in the excitation from 230 to 115 volts produces no change in the timing that can be measured by a stop watch. The timing is also unaffected by changes in temperature. It may therefore be said that these relays provide a time element which remains constant under all operating conditions and which may readily be adjusted to suit individual requirements.

The control system provides time-limit acceleration when the motor is started from rest. On equipments used for reversing service, the system provides another essential feature, viz., current-limit control of the plugging contactor which short-circuits the plugging resistor. On any reversing control it is essential that, when the motor is being started from rest, the plugging contactor shall close immediately after the reversing contactors. It is also essential that, when the motor is being reversed, the plugging contactor shall not close until the motor is practically at standstill. Definite time-limit control of the plugging contactor would not be satisfactory; for if it could be adjusted to close the plugging contactor properly when starting from rest, it would close it too quickly when the motor is reversed. Likewise, if it could be properly set for plugging, proper response of the motor to movement of the master-switch handle from the "off" position could not be obtained because of the time delay before the short-circuiting of the plugging resistor. The torque developed at standstill by a series motor with the usual starting and plugging resistor connected in the armature circuit is approximately only 60 per cent; whereas, that developed when the plugging resistor is short-circuited is approximately 200 per cent or over 3½ times as great. These facts explain why it is essential to have the plugging contactor close immediately after the reversing contactor when the motor is started from rest.

The control of the plugging contactor is obtained by the relay illustrated in Fig. 2. This relay differs from the accelerating relay only by the addition of contacts at *F* and *G* which make the relay normally open instead of normally closed. The coils are identical and it should be mentioned here that only one size of relay coil is required for a given line voltage, regardless of the size of the motor which is to be controlled.

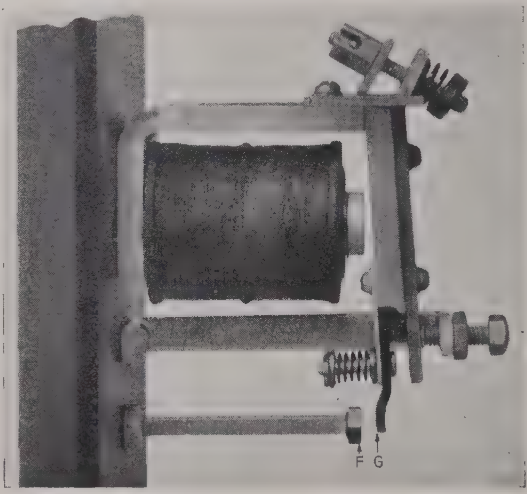


Fig. 2. Relay for Control of Plugging Contactor

An elementary diagram of connections of a reversing controller is shown in Fig. 3. In this sketch the reversing contactors are labelled *1F*, *2F*, *1R*, and *2R* and the circuit-breaker contactor, *CB*. The plugging contactor is *P*, and *1* and *2* are the accelerating contactors. The relays which control the closing of the plugging contactor are *PF* and *PR*, *PF* being effective when the master switch is moved to the "forward" position and *PR* when operating in reverse. The timing relays *1A* and *2A* control contactors *1* and *2* respectively.

With the master switch in the "off" position, the circuit breaker contactor *CB* will close when the line switch is closed. This contactor is held closed by an interlock, It will open on failure of voltage or upon tripping of the overload relays, but having once opened it cannot again be closed until the master-switch handle is first returned to the "off" position.

Assuming that the operator moves the master-switch handle to a "forward" position when the motor is at standstill, the sequence of operations will be as follows: Contactors *1F* and *2F* will close, allowing current to flow through the motor and resistor. A voltage equal to the IR drop across the resistance *R1—R2* will immediately be impressed on the coil of relay *1A*. This will pick up its armature and open the contacts. Simultaneously, the contacts of timing relay *2A* will be opened due to a voltage equal to the IR drop across resistance *R1—R3* being impressed on its coil. When contactor *1F* closes, an interlock closes the coil circuit of relay *PF* and the voltage then impressed on this relay coil is equal to the algebraic sum of the IR drop across the resistance *R1—R2* and the counter electromotive force of the motor. As a thorough understanding of this action is essential, reference should be made to Fig. 4. The direction of current flow is always from *L1* to *L2* as shown by the dotted arrows. The voltage drop across the resistor is in opposition to the flow of current and should, therefore, be considered as having a direction as shown by the full-line arrows. When the motor is being started from rest, its counter electromotive force opposes the flow of current and is therefore in the direction indicated. It is thus seen that the voltage impressed across the coil of relay *PF* is the sum of the voltage drop across resistance *R1—R2* and the counter electromotive force of the motor. This voltage is sufficient to pick up the relay armature and close the contacts. This causes the plugging contactor to close, as its coil circuit is energized by the closing of the relay contacts. The action is the same when starting in the reverse direction except that relay *PR* (Fig. 3) is energized through an interlock on contactor *1R* and effects the closing of the plugging contactor.

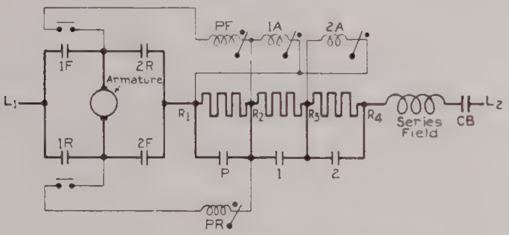


Fig. 3. Elementary Diagram of Connections of the Magnetic-time Control System

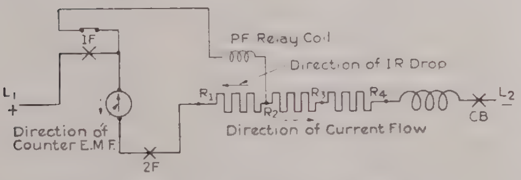


Fig. 4. Current and Voltage Conditions in the Controller When Motor is Started from Rest

It is evident, therefore, that when starting from rest the plugging contactor will be closed immediately after the forward or reverse contactors. The closing of the plugging contactor short-circuits the coil of relay *1A*. After a definite time, this relay armature releases and closes its contacts, thus closing contactor No. 1. The closing of contactor No. 1 short-circuits the coil of relay *2A* which allows its armature to be released after a definite time, thus closing contactor No. 2.

When the motor is reversed, the action of the *PF* or the *PR* relay is somewhat different. Assume that the motor is running in the forward direction and that the master-switch handle is moved to the "reverse" position. The accelerating, plugging, and forward contactors will open when the master switch passes through the "off" position. Contactors *1R* and *2R* will be closed in the "reverse" position and conditions will then be as shown in Fig. 5. The voltage impressed on the coil of relay *PR* is the algebraic sum of the IR drop across the resistance *R1—R2* and the counter electromotive force. Inasmuch as the motor was running in a forward direction when the reverse contactors closed, the counter electromotive force is still in the same direction. It will be noted, however, that this direction is now, on account of the change in connections, opposite to the IR drop and therefore the actual voltage on the relay coil is the difference between the counter electromotive force and the IR drop. This difference will be practically zero, and therefore the contacts of relay *PR* will not be closed. As the speed of the motor armature decreases, the counter electromotive force decreases. The voltage across the relay coil therefore increases until it is sufficient to close the relay contacts at the time that the motor armature is practically at standstill.

As soon as the reversing contactors close, the contacts of relays *1A* and *2A* are opened so that they are ready to function as soon as the plugging contactor is closed. The action of the control which occurs after the plugging contactor has closed is the same, regardless of whether the motor is being started from rest or has been plugged.

Fig. 7 is a graphic ammeter record of the current input to a 70-h.p. 230-volt series motor with a reversing controller. The motor drives a rail-mill table approximately 75 ft. long, consisting of 20 rollers. Extremely rapid operation is not essential to maintain the desired production and the timing of the relays has therefore been adjusted to give a rather long delay. The interval of time between closing of the forward or reverse contactors and the closing of the last accelerating contactor is approximately 1.8 sec. when the motor is started from rest. When the motor is plugged, the interval is about 3.75 sec.

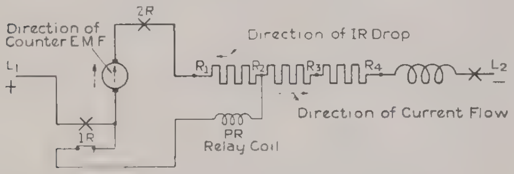


Fig. 5. Current and Voltage Conditions When Motor is Plugged

The control previously used with this motor was equipped with series accelerating contactors. It was found necessary, in order to take care of maximum load conditions, to so adjust the series contactors that the current peaks were between 700 and 800 amp. Since the installation of the new controller, the current peaks have been reduced to those shown by Fig. 7. The peaks are, of course, higher when starting a cold mill but soon come down to a maximum of about 350 amp.

Fig. 6 is shown to illustrate a fairly rapid cycle obtained by short timing of the relays. Here the motor is accelerated in about 1 sec. and is reversed in approximately 1½ sec.

Fig. 8 shows a typical control panel. It consists of three bases moulded from a compound that has been especially developed for this purpose, and which is superior to slate. This compound is of asbestos, combined with a high grade insulating material. The impregnating compound and the method of impregnation and treatment were developed in the Research Laboratories at Schenectady, and the product has been given exhaustive tests.

The appearance of the front of the panel is identical with that of slate but the material has very much greater resistance to mechanical shock and has better electrical qualities than slate. The greater shock-resisting power permits the use of thinner and consequently lighter weight panels, which serves to decrease the total weight and cost of the equipment.

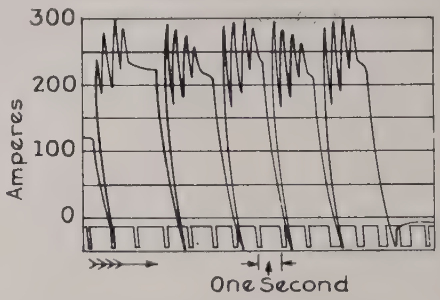


Fig. 6. Ammeter Record of Current Peaks Under Heavy Load, Showing Fast Acceleration with Mill Type Controller

The resistors shown in Fig. 8 employ what is known as the unit box type of construction; only one size of cast iron grid with three-point support is used in each frame and all grids are connected in series. It will be noted that the four equally spaced terminals are all on one side of the box. This simplifies the wiring to a considerable extent. For motors ranging from 30 to 150-h.p. capacity only six different boxes are required.

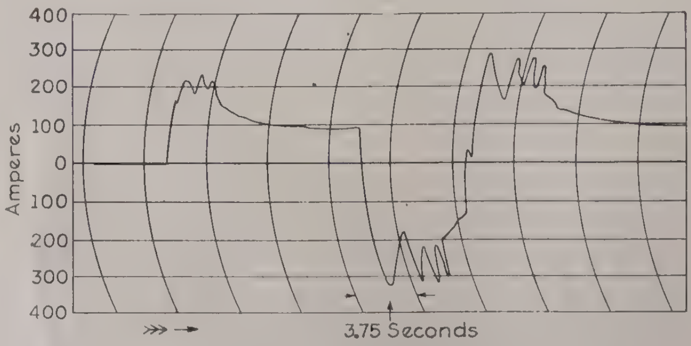


Fig. 7. Graphic Ammeter Record, Showing Input to 70-h.p., Series Mill Motor Connected Through a Magnetic Controller

This standardization of boxes makes possible quick repairs by substituting for the damaged boxes complete new boxes which will be mechanical and electrical duplicates.

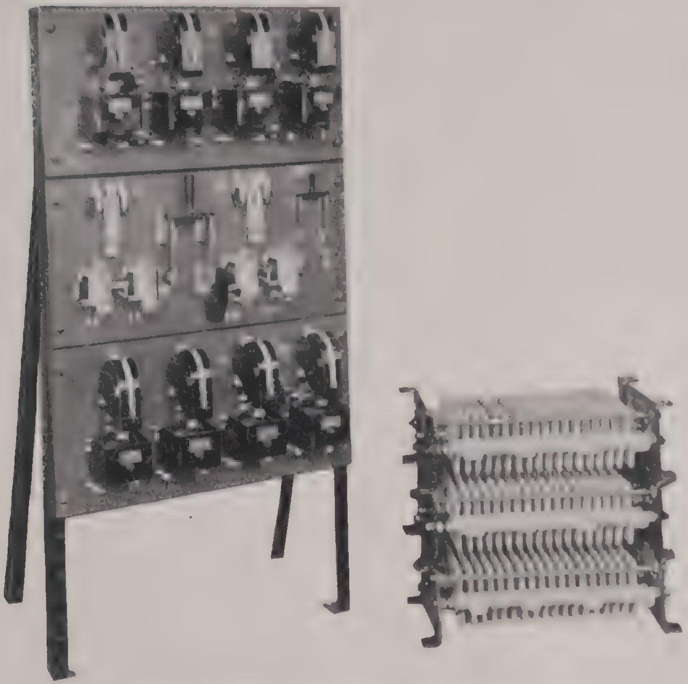


Fig. 8. Typical Magnetic Type Control Panel and Unit Box Resistor

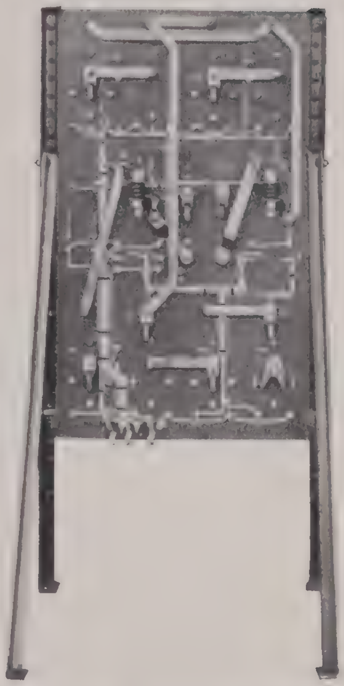
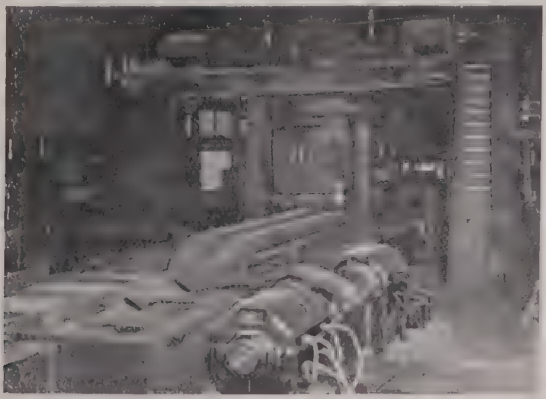


Fig. 9. Back View of Panel, Showing Motor and Control Circuit Wiring

The damaged boxes can then be sent to the repair shop and the individual grids replaced when convenient. In order to make the identifying of duplicate boxes readily possible, the end frames can be painted various colors, a single color being used for all boxes containing the same sized grid.

When greater current-carrying capacity than that of the single grids connected in series is required, boxes or sections of boxes may be connected in multiple.



Installation of Auxiliary Steel Mill Motors to which the New Magnetic-time Control System is Especially Adapted

The Adjustable-speed Alternating-current Motor with Shunt Characteristics

By H. C. Uhl

Industrial Engineering Department, General Electric Company

Into the extensive family of electric motors of widely varying sizes and characteristics, there has been born a new child which has already shown promise of being a prodigy. This motor possesses the much-sought combination of alternating-current adjustable-speed shunt-characteristic features and yet is a relatively simple and compact machine. Due to its attractive operating characteristics, this three-phase motor finds application in a wide and varied range of industries. The design features of the motor and details of its different applications to various industries are outlined in this article.—Editor.

The development of satisfactory alternating-current adjustable-speed motors, and combinations for obtaining adjustable speed, has been given much attention both in Europe and in this country because of the quite general use of alternating current and because the usual types of alternating-current motors give constant speed or approximate constant speed.

The alternating-current adjustable-speed brush-shifting motor described in this article has shunt characteristics; that is, its change of speed is only moderate as compared to the change in load. It is sometimes known as the Schrage motor from its inventor, K. H. Schrage of Sweden. As developed in this country by the General Electric Company, it is known as the type BTA motor and is built to supply the demand for an alternating-current motor having shunt characteristics, which will also provide adjustable-speed features without unduly complicating the machine. Such a motor may be used for a wide field of applications where its characteristics are desirable or necessary and where alternating current is the only available power supply.

Motors of this type are at present available for use on three-phase 60-cycle circuits for 220, 440, or 550 volts, and are usually built for a three-to-one speed range with a horsepower output rating directly proportional to the speed. They can also be built for other speed ranges and frequencies, as well as for use on two-phase circuits. Ratings from 3 to 50 h.p. are now available and larger sizes have been built. The three-phase 60-cycle motors from 3 to 12½ h.p. inclusive have a full-load speed range from 550 to 1650 r.p.m.; and the motors from 20 to 50 h.p. inclusive have a full-load speed range from 415 to 1250 r.p.m. The horsepower given is that at the highest full-load speed. It is possible to obtain more horsepower per pole from the 25-cycle motors for a given speed range than from the 60-cycle motors.

General Characteristics

In sizes from 3 to 50 h.p. with a speed range of three-to-one, for use on three-phase 60-cycle low-voltage lines, the motors possess the following general characteristics:

Speed

The motors have a full-load speed range of three-to-one, the slip reducing the top and bottom speeds and all intermediate speeds as with an induction motor. The change in speed from no load to full load, however, is greater than for an induction motor, but is substantially the same in revolutions per minute over the speed range of the developed ratings, except at and near synchronous speed where it is less. At high speed this amounts to 5 or 10 per cent of the speed in question, and at low speeds to 15 or 20 per cent of the speed in question, depending on the rating of the motor.

Starting Torque, Maximum Torque, and Starting Current

With the brushes in the low-speed position the motors may be thrown directly on the line and will give from 150 to 250 per cent of normal torque at starting with only 125 to 175 per cent of full-speed line current. The maximum running torque at low speed is 150 to 250 per cent of normal torque, and increases as the speed is increased. For the high-speed position, the maximum running torque is 300 to 400 per cent of normal torque.

With the brushes in the high-speed position the starting torque is approximately 110 to 150 per cent of normal torque, although the static torque may be materially less than these values due to the position curve, and the starting current is approximately 400 to 600 per cent.

Starting Conditions and the Use of Secondary Resistance

In view of the foregoing differences in starting torque and starting current values for different brush positions, it is desirable that the motor be started with its brushes in the low-speed position where the starting current is extremely low and the starting torque very high. By the use of secondary resistance, it is possible to start in any brush position with low starting current and good starting torque. Nevertheless, it is seldom necessary to use secondary resistance for starting as in most applications it is possible to start the motor with the brushes in the low speed position. Where the amount of speed range is small, however, it would be desirable to use secondary resistance even with the brushes in the low-speed position because, as synchronism is approached, the starting current values approach those of an ordinary induction motor.

It is possible to use secondary resistance to obtain lower speeds than the rated speeds as in wound-rotor induction motors. In the brush-shifting motor, however, it is necessary to keep each phase of the resistance independent. Secondary resistance is frequently used to obtain a creeping speed of one-half the otherwise minimum speed, for applications such as textile printing (for pattern adjustment and threading in) where the motor is loaded during this period. The secondary resistance is used in conjunction with contactors, which when closed short-circuit the resistance and when open insert the resistance. These contactors are controlled by a push-button station, or a small master switch.

When secondary resistance is used, an amount to give a certain reduction in revolutions per minute with full torque at low speed will give approximately the same decrease in revolutions per minute when used with the same torque at other speeds.

It is also necessary to use secondary resistance when the motor is to be plugged.

Direction of Rotation

The motors will operate continuously in either direction, i.e., clockwise or counter-clockwise facing the commutator, with the brush mechanism set for the rotation desired. They may be reversed by interchanging two line leads as on an induction motor. Reverse operation should be permitted only for short periods, as the torque, power-factor, and heating characteristics of the usual motor in reverse, with brushes set for forward rotation, are not so good as when the brushes are set for the desired rotation. The brushes may readily be set for either direction of rotation.

The motor may be arranged for reversing service without resetting the brushes, by permitting a decrease in the starting torque and in the low-speed power-factor.

Efficiency and Power-factor

For ordinary sizes of motors the high-speed full-load power-factor will be from 95 per cent lagging to unity. The low-speed full-load power-factor will be approximately 65 to 70 per cent lagging. The low-speed light-load power-factor, however, will be higher than the low-speed full-load power-factor. The power-factor at synchronous speed is determined by the characteristics of the machine when operating as a plain induction motor. It is thus apparent that where the motor draws the most energy from the line, i.e., at high speed, the power-factor is the best.

The efficiency of this shunt-characteristic motor remains nearly constant over the greater part of its speed range, but is somewhat lower at the low speeds. The efficiency at synchronous speed and high speeds will be slightly lower than for an induction motor of the same horsepower at synchronous speed. The average efficiency is high as compared to that of wound-rotor induction motors with secondary resistance, or when compared with direct-current motors operating from alternating-current—direct-current conversion apparatus.

General Considerations

The brush-shifting motor has a very low voltage on the commutator which is particularly advantageous for certain applications. This voltage is the same when starting or running.

Variations of line voltage do not materially affect the speed as with direct-current machines, the motor being similar to an induction motor in this respect.

Neither do temperature variations affect the speed as with direct-current shunt motors.

Details and Operation

The motor may in some respects be compared with the wound-rotor induction motor, although it should be borne in mind that the characteristics of this brush-shifting motor are quite different from the characteristics of the wound-rotor induction motor, as is shown later.

The general construction of the motor is shown in Figs. 1 and 2. The schematic diagram in Fig. 3 shows how the windings are arranged. The primary winding is in the rotor instead of in the stator, as is the case in the wound-rotor induction motor, and is connected to the power supply through collector rings. The secondary winding is in the stator, which again differs from its position in the wound-rotor induction motor. The secondary winding has each phase independent. In addition, this shunt-characteristic motor has a second winding in the rotor similar to a direct-current armature winding which, in this case, also connects to a commutator. This winding, known as the adjusting winding, is placed nearest the air gap to obtain the benefit of lower reactance and thereby give better commutation.

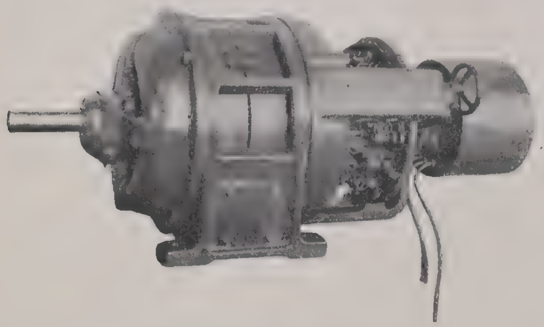


Fig. 1. Adjustable-speed Brush-shifting 30/10-h. p. Motor, Wound for 550 Volts, 1250/415 r.p.m.

The motor is provided with two brush yokes, one located at each end of the commutator, so arranged as to shift in opposite directions. One end of each phase of the secondary winding is connected to brushes on one brush yoke and the corresponding other ends of the secondary winding are connected to brushes on the other yoke. Bus rings on the yokes keep the phases separate and permit the use of several studs per phase. With three-phase power supply for the primary in the larger sizes of motors, it is frequently desirable to use a different and larger number of phases in the secondary, and a corresponding spacing of the brushes on the commutator. This is possible since there is no electrical connection between the primary and the secondary. Better commutation and better operating characteristics are thereby obtained.

The primary winding in the rotor which connects to the power supply through the collector rings generates the working flux in the machine. This flux is substantially constant since the line voltage and line frequency are substantially constant. Since the adjusting winding, which connects to the commutator, is placed in the same slots as the primary winding, a voltage of constant value and at line frequency is induced in it by the primary flux, by transformer action. The commutator changes the frequency from line frequency to slip frequency, which is the frequency of the secondary of the machine.

Thus the voltage between two brushes properly located on the commutator will depend upon the number of commutator segments between them or, in other words, upon the number of turns of the adjusting winding included between the two positions on the commutator where the brushes are located. Obviously, the minimum value of this voltage will be zero when the two brushes being considered are together on the same commutator segment, thus including no portion of the adjusting winding. Also, the voltage will have its maximum value when the two brushes are one pole arc or 180 electrical degrees apart on the commutator. Now assume one of the brushes to be connected to one end of a secondary phase and the other brush to be connected to the other end of the same phase; and likewise for the other brushes or groups of brushes and secondary winding phases. For the condition where the brushes are together on the same commutator segment, it was noted that no portion of the adjusting winding was included and it is apparent that the secondary winding is short-circuited. Thus we have the conditions existing in an ordinary wound-rotor induction motor with short-circuited secondary, and the motor will run as an induction motor with its speed depending upon the frequency of supply and upon the number of poles of the motor.

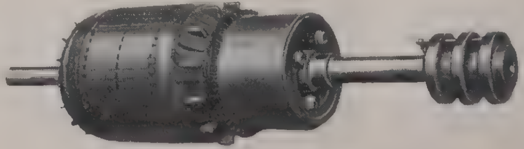


Fig. 2. Armature of Motor Shown in Fig. 1

If the brushes of the motor are now moved apart, some commutator segments and consequently a portion of the adjusting winding will be included in series with the secondary winding, thus impressing a voltage at slip or secondary frequency across the secondary winding. If the brushes are properly located on the commutator, this voltage will cause an increase or decrease in the speed of the motor because the secondary winding must generate a counter voltage with proper phase rotation to balance the voltage impressed upon it by the adjusting winding. The speed of the motor must change until the voltage generated by the secondary winding (generated by its cutting the primary flux) balances the impressed voltage with just enough difference to permit sufficient current to flow to develop the required torque.

When the gear shaft of the brush-shifting mechanism is turned in one direction the speed is raised, and when turned in the opposite direction the speed is lowered. The motor operates both above and below the induction-motor synchronous speed.

If the brushes of the motor are shifted approximately 90 electrical degrees around the machine, that is, such that the same two brushes are together on a segment 90 electrical degrees from the position referred to, and they then be moved apart as before, the speed would not change but the power-factor would. Therefore, by compromising between the two positions speed control is obtained, and also some control over the power-factor within the capacity of the windings.

It may be well to mention that if the motor is running at 150 per cent of synchronous speed, the slip energy will be 50 per cent of the power developed at synchronous speed with the same torque and the adjusting winding need be made only 50 per cent of the synchronous horsepower capacity of the secondary or stator winding. With such an adjusting winding the machine can be operated either 50 per cent above or 50 per cent below its synchronous no load speed thereby giving a three-to-one speed range.

The two brush yokes are connected to the shifting mechanism by means of gears. For hand control of the brush shift, a handwheel is placed on the gear shaft as shown in Fig. 1. If hand control is desired from a remote point, a conveniently located handwheel bracket with chain and sprocket is connected to a sprocket on the gear shaft of the shifting mechanism. The handwheel bracket is provided with a pointer geared to the mechanism and a dial so that it may be calibrated in any way desired. The brushes may also be shifted by means of a pilot motor and gear train mounted on the motor and connected to the brush-shifting mechanism. When using the pilot motor mechanism for brush shift, the speed of the motor may be controlled from a distance by push buttons or by various types of automatic regulators.

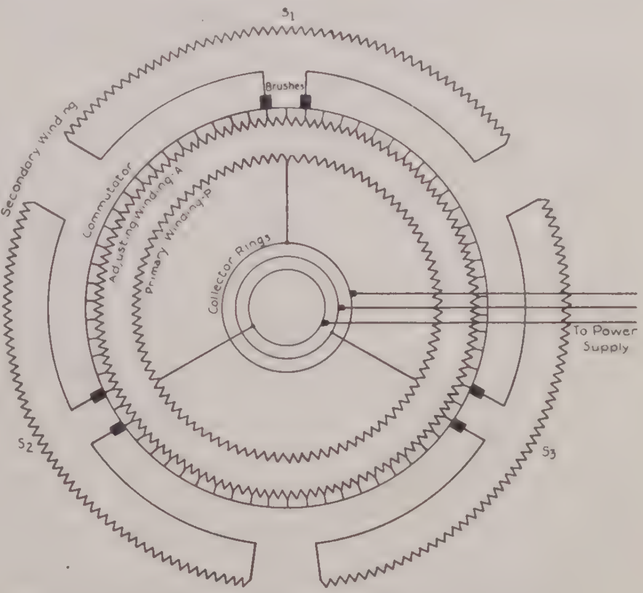


Fig. 3. Schematic Diagram of Adjustable-speed Shunt Motor. The stator contains only the secondary winding, each phase of which is connected independently between two commutator brushes. The rotor has two windings. The primary winding is connected to the collector rings deriving power therefrom. The adjusting winding is placed in the same rotor slots and connects to the commutator

Control

Very simple control can be used since it is usually possible to throw the motor directly on the line with the brushes in the low-speed position. The motor is connected to the source of power in the same manner as many induction motors. For hand and remote hand control of the brush shift, an enclosed magnetic switch⁽¹⁾ with thermal overload and undervoltage protection may be used,

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(1) Identified by the trade designation "CR-7006."

and may be operated by means of a stop-start push-button station. When using the pilot-motor type of control, a modified magnetic switch(2) with thermal overload protection may be used with a push-button station marked start, stop, fast, and slow, in addition to the pilot motor, gear mechanism, and small pilot-motor transformer. With this arrangement the brushes will automatically return to the low-speed position on stopping or, if power fails, they will move to the low-speed position on re-establishment of power.

With pilot motor control a transformer is required for all voltages of the main motor, because a low-voltage pilot motor is used so as to increase the factor of safety in the device. The small pilot motors are built for 70-volt operation and the transformers are supplied with taps. A limit-switch arrangement is mounted on the brush mechanism of the main motor, to limit the travel of the brushes in either direction.

When secondary resistance is used with these brush-shifting motors of the smaller sizes (3 to 50 h.p.) an enclosed magnetic switch(3) may be used; one three-pole switch for motors with three-phase secondaries and two three-pole switches for motors with six-phase secondaries. A master switch or a push-button station may be used for operating these contactors.

Comparison with Other Types of Motors and Combinations

In many plants much of the work can be accomplished by the use of constant-speed motors and therefore squirrel-cage induction motors are largely employed. For those drives requiring adjustable speed, where alternating current is the major power supply it was formerly necessary to use motor-generator sets or synchronous converters to convert from alternating current to direct current, for the adjustable-speed drives, and then use direct-current motors. If it is feasible to use the brush-shifting, shunt-characteristic motor, the alternating-current power supply at low voltage may be used for the adjustable-speed drives also. In this manner the plant wiring is simplified, the overall efficiency is increased in many cases, and the necessity of increasing the capacity of the alternating-current to direct-current converting apparatus when more drives are added is eliminated.

When a large number of adjustable-speed drives are required it may often be more advantageous to install the alternating-current to direct-current converting apparatus in a large unit and use direct-current motors. Cases of this sort must be carefully considered to see which scheme works out the better. The brush-shifting shunt motor is inherently a constant-torque motor and this must also be considered, especially where the application requires constant-horsepower adjustable-speed motors. For constant-horsepower applications this type of motor is at a disadvantage since it is necessary to use a motor which will give the required horsepower at low speeds which thereby gives a large excess capacity at higher speeds.

The double-range Scherbius system, the Kraemer or Rotary Converter System, the Brush-shifting Converter System, and the Frequency Converter System, used in conjunction with large wound-rotor induction motors, give adjustable speed with shunt characteristics in a very satisfactory manner. These schemes are practicable however for comparatively large motors only, since considerable auxiliary apparatus is required and the amount of speed range possible in this manner is rather limited, although sufficient in most cases where these equipments are applicable, as for some steel-mill main-roll drives.

It is possible to use the wound-rotor induction motor with secondary resistance for many applications, but it must be kept in mind that this type of motor with secondary resistance gives a series characteristic, i.e., the speed changes materially with load and at no load with an ordinary amount of resistance in the secondary the motor will operate near synchronous speed. Each controller point will give a definite speed for a given load, the speed varying with the load. The efficiency at low speeds is quite low and it is not usually considered practicable to obtain more than a two-to-one speed range in this manner due to the possibility of instability and stalling at low speeds.

When only a small speed reduction is desired with small size motors, the wound-rotor induction motor with secondary resistance may be used to advantage providing the series characteristic is acceptable or the load quite steady. This would be cheaper than using the brush-shifting shunt motor. Where it is possible to use wound-rotor motors with secondary resistance, the advantage in efficiency that the brush-shifting motor has at low speeds is of course reduced if operation at low speeds is infrequent, nevertheless the latter motor still has the advantage of a much greater speed range with perfectly stable operation and the advantage of more uniform speed change.

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(2) Identified by the trade designation "CR-7006 Y-1"
(3) Identified by the trade designation "CR-7002."

The brush-shifting, three-phase, quarter-phase, and single-phase series motors(4) are adjustable varying-speed motors, also giving speed change by brush shift. But, having a series characteristic, i.e., a large change in speed with change in load, their use is restricted to those applications where the series characteristic is not objectionable. The principal application of the brush-shifting series type of motor with its auxiliary rotor transformer has been and still is for forced and induced draft fans in power plants, for mine ventilating fans, and for centrifugal pumps. In small sizes, these motors were used for various textile applications where adjustable speed was required. Here the motor was applied satisfactorily, in spite of its series characteristics, because no other type of alternating-current adjustable-speed motor of small size was available. For textile applications the brush-shifting shunt type of motor is now being used and will gradually include more applications in this industry due to the better characteristics and greater speed range possible; but for forced and induced draft fans in power plants, mine ventilating fans, and some centrifugal pump applications where the horsepower per pole is high, the series type of brush-shifting motor will still be used as it has proved over many years to be particularly suitable.

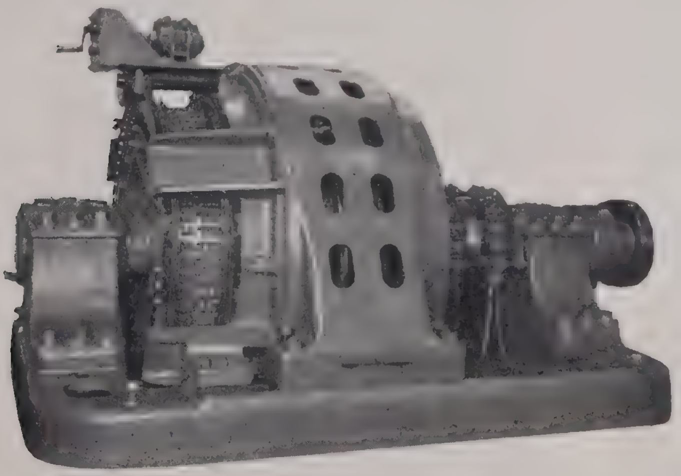

Fig. 4. Brush-shifting Motor for Steel Mill Use

It is possible to use multispeed squirrel-cage induction motors in some cases, but this type of motor gives definite speeds corresponding to the poles of the stator winding or windings. With the brush-shifting shunt motor a smooth change in speed is obtained throughout the speed range. If several definite speeds are satisfactory, the multispeed motor will be the cheaper.

For certain applications the multispeed wound-rotor induction motor may be used satisfactorily. The motor will give definite synchronous speeds corresponding to the poles of the stator winding and will permit a variation from each definite speed by the use of secondary resistance. For any particular speed used, the characteristics in general are the same as for the ordinary wound-rotor motor. Multispeed wound-rotor motors are usually built for only two synchronous speeds, due to the number of collector rings required.

Applications

The three-phase adjustable-speed brush-shifting motor having shunt characteristics is suitable for application to a wide range of industries, a few examples of which are shown in Figs. 4 to 12.

It is well to consider that this type of motor is inherently a constant-torque motor, i.e., the horsepower is directly proportional to the speed, and for a given speed range has a definite possible limit per pole. For a given speed range, more output per pole can be obtained from the 25-cycle motors than from the 60-cycle motors.

Motors of this type are particularly suited for the following conditions:

(1) Where adjustable speed with shunt characteristics is necessary and alternating-current power is the only supply.

(2) Where large speed range is required and where uniform speed change is desired rather than speed change in definite steps as furnished by wound-rotor induction motors having secondary resistance or by multispeed induction motors.

(3) Where it is desirable to operate at low speed much of the time, with the possibility also of operating at higher speeds.

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(4) Identified by the trade designation "BTS," "BQS," and "BSR."

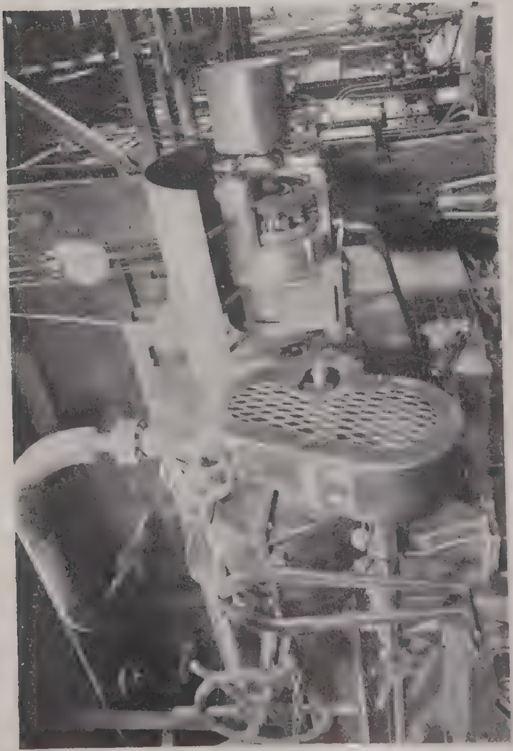

Fig. 5. Chain Grate Stoker Driven by a 10/2.5-h.p., 440-volt Motor

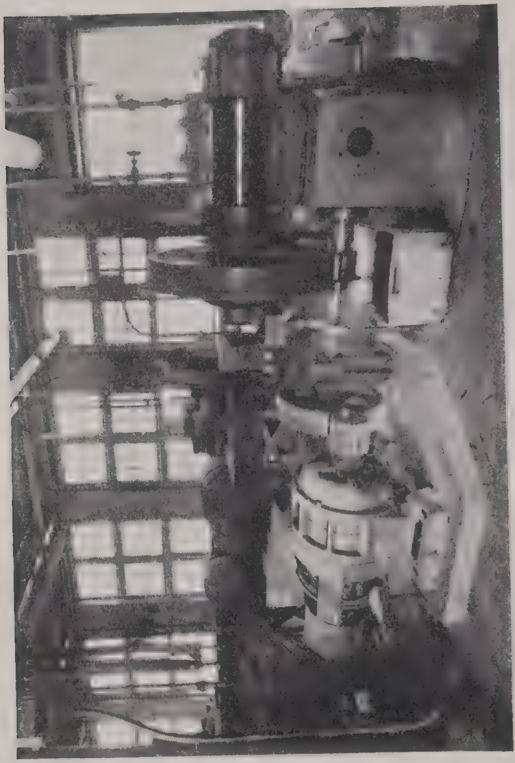

Fig. 6. Tube Machine in a Rubber Mill Driven by a 30/10-h.p., 1250/415-r.p.m. Motor

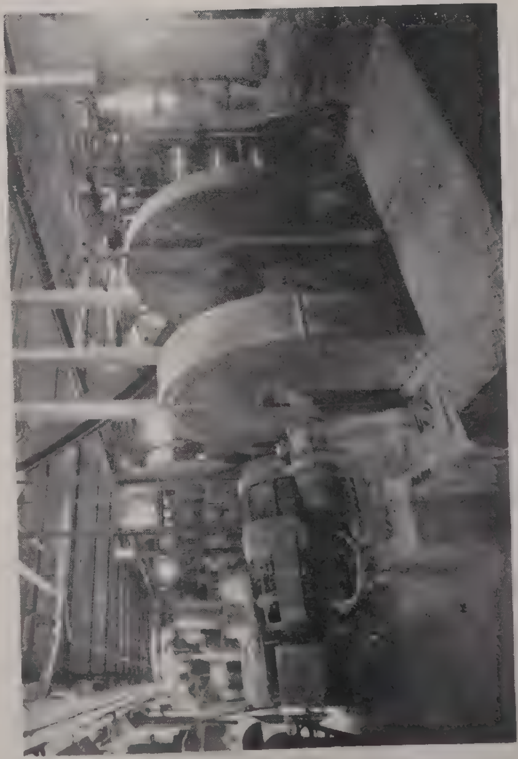

Fig. 7. Tread Calender in a Rubber Mill with Adjustable-speed Electric Drive

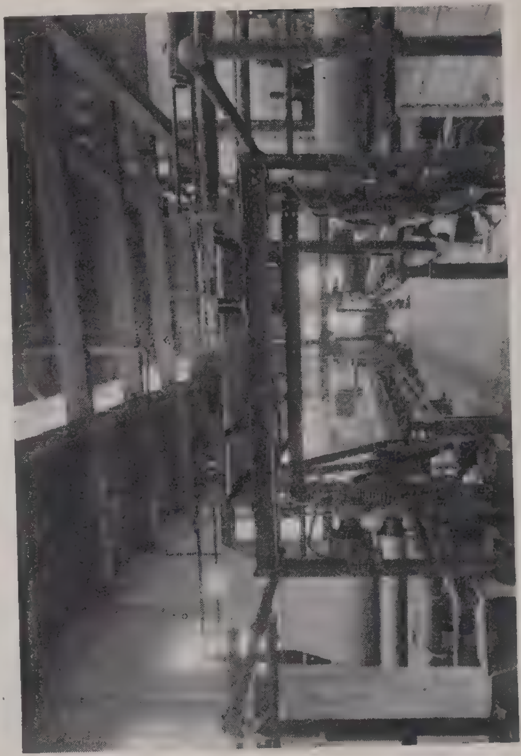

Fig. 8. Two Tandem-driven Mercerizing Ranges Each Driven by Two 550-volt Brush-shifting Motors

Textile Industry

In the textile industry the motor has been applied to cloth printing machines, single and tandem tentering ranges and mercerizing ranges, textile calenders, washers, squeezers, and limers in finishing plants.

For cloth printing machines the motor has been used with hand control of brush shift, remote hand control, and pilot motor control with push buttons as desired. It is usually necessary to obtain a low creeping speed equal to about one-half of the minimum rated speed for pattern adjustment and threading in. Jogging control is also frequently desired. The low creeping speed is obtained by the use of secondary resistance, contactors, and a push-button station as has been described.

For single tentering and mercerizing ranges, textile calenders and washers, squeezers and limers, the control usually consists of a magnetic switch and push-button station. The brushes may be shifted by hand, remote-hand mechanism, or pilot motor as desired. In some cases other control may be used.

For tandem tentering and mercerizing ranges a complete control scheme has been worked out to obtain the speed control of the follower motor either mechanically or electrically.

The follower motor, in the case of the tandem arrangement using two motors, is the motor driving the part of the range into which the cloth first comes. The leading motor is that driving the part of the range into which the cloth progresses. The control is usually arranged so that both motors are started and stopped at the same time by means of push-button stations, and frequently is arranged for individual operation of either motor. Between the follower and leading motor a floating roll, known as the compensating roll or gate, is located between two fixed rolls. On both the mechanical and electrical scheme for controlling the speed of the follower motor, the leading motor is equipped with a pilot motor and push buttons to control the brush shift and consequently the speed of this motor. The speed of the follower motor, in either case, is controlled by the movement of the compensating roll. As the speed of the leading motor is increased, the compensating roll rises which causes the speed of the follower motor to increase. As the speed of the leading motor is decreased, the compensating roll lowers which causes the speed of the follower motor to decrease.

For the mechanical control scheme (which is used where the location of the follower motor is convenient to the compensating roll) the movement of the compensating roll by means of sprockets and chain, mechanically shifts the brushes of the follower motor and thus controls its speed.

For the electrical control scheme, the movement of the compensating roll operates a limit switch combined with an intermittent motion device driven from the rolls. The limit switch energizes a pilot motor which shifts the brushes of the follower motor and controls its speed.

Either scheme gives control of the follower motor without hunting. Both are in successful operation, although the mechanical control where the location of the machines permits its use is the cheaper. With the electrical control the speed of either motor may be adjusted individually and the brushes of both motors return to the low-speed position automatically when stopping, or after power is re-established after failure or when shutting down.

Rubber Industry

In the rubber industry the motor has been applied to tube machines and to rubber calenders.

For tube machines control consisting of a magnetic switch and push button is usually used. Hand control of the brush shift may be used although pilot-motor control of the brush shift is considered more desirable since with the latter the operator does not have to leave his work to adjust the speed or to move the brushes to the low-speed position before starting.

For rubber calenders special control is used. A pilot motor controlled by push-button stations shifts the brushes. Provision is made for quick stopping by means of either a solenoid brake or by plugging, or both. When plugging is used a device attached to the motor shaft prevents the operation of the motor in the opposite direction after it has come to rest. Secondary resistance is used when plugging. When the normal low speed is not slow enough for threading in, a still lower speed may be obtained by the use of secondary resistance.

Oil Refineries

In oil refineries the motor has been used for driving cross-process pumps.

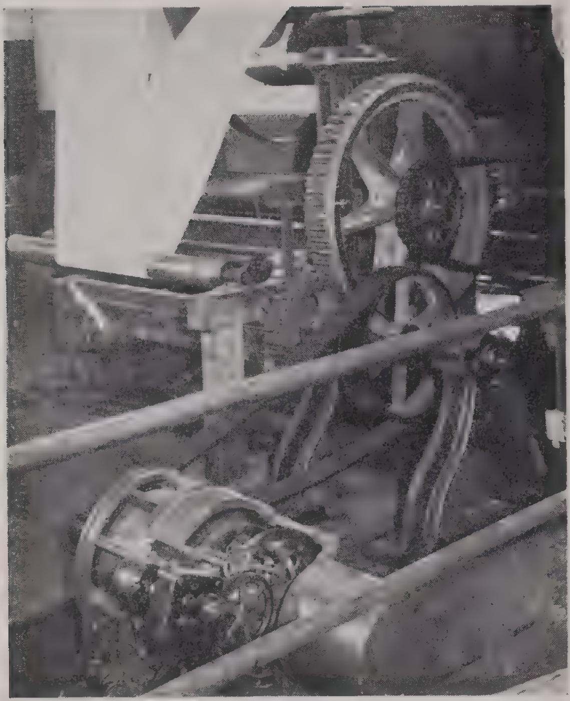

Fig. 9. Part of a Tandem Driven Tenter Range. 550-volt, 12.5/4.17-h.p. follower motor driving mangle, padder and cans

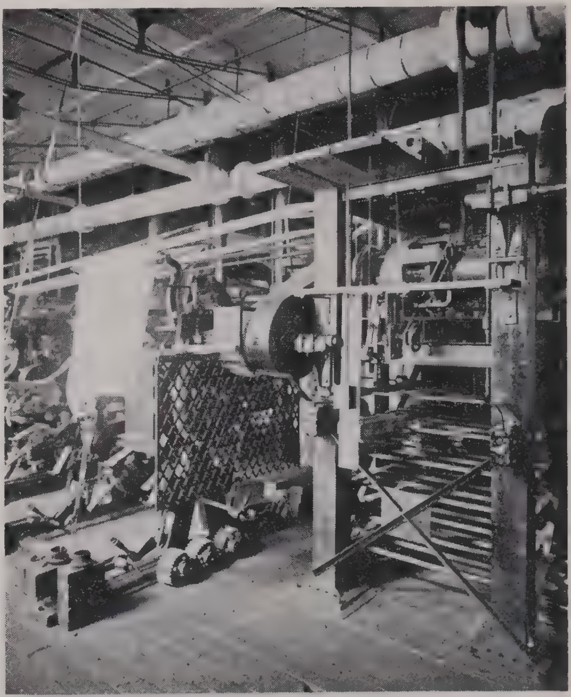

Fig. 10. Cloth Printing Machine Driven by a 25/8.33-h.p. 1250/415-r.p.m., 550-volt Motor

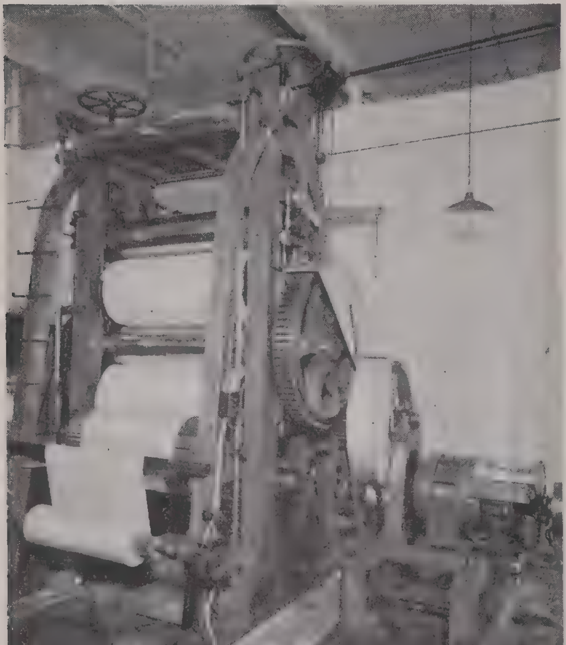

Fig. 11. Five-roll Textile Calender with Adjustable Speed Motor Rated at 25/8.33 h.p.

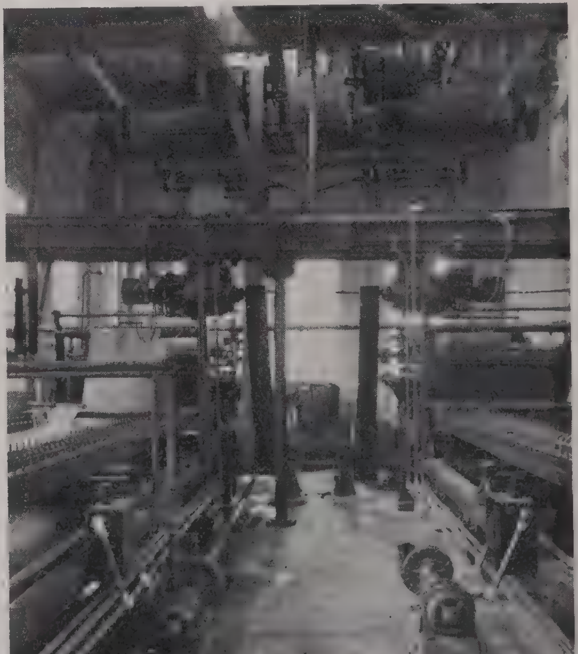

Fig. 12. Part of Two Tandem-driven Mercerizing Ranges. Leading motors of 20/6.67 h.p., 1250/415 r.p.m., drive tenter frame and recuperator

Central Stations and Boiler Plants

The chief application of the motor in central stations and boiler plants has been for stoker drives and for forced and induced draft fans.

For stokers, control of speed by hand wheel or pilot-motor control of brush shift by push buttons has been used but automatic control by pilot motor and some form of regulator is easily applied. Drip covers to protect the windings and commutator from all falling material are desirable in this type of installation.

For forced and induced draft fans, speed control either by pilot motor and push buttons or by hand control of brush shift has been used. Automatic control from damper or steam pressure has also been used.

Rolling Mills for Steel and Non-Ferrous Metals

In these industries the motor has been applied to steel-mill main-roll drives, aluminum foil machines, and wire drawing machines.

Two large motors for use on 25-cycle lines have been applied to main roll drives in a steel mill and have proved very satisfactory. They are of steel-mill construction, and have stator movement and thrust collars, forced ventilation, temperature coils in stator, pilot-motor control of brush shift, electric tachometer for reading the speed, and are arranged for plugging duty. Normal starting is accomplished by throwing them directly on the line with the brushes in the low-speed position. Secondary resistance is supplied for plugging duty. Fig. 4 shows one of these motors.

A number of brush-shifting shunt motors have been used for driving aluminum-foil machines where it is desired to start the process at low speed to prevent the rolls, etc., from overheating, and then after the rolls have gradually become heated and the foil is coming through the rolls satisfactorily to speed up the motors and greatly increase the output.

Some of these motors have been applied to wire drawing machines.

Pumps, Fans, Centrifugal Compressors

The motor has been successfully applied to the driving of centrifugal pumps and centrifugal compressors, and fans other than those in central stations and boiler plants which have been referred to in the foregoing.

For centrifugal pumps, etc., it is well to keep in mind that, because the horsepower required varies approximately as the cube of the speed, the low speed obtained will be slightly higher than the rated speed at full torque. For applications requiring only a small speed reduction, motors developed for three-to-one speed range will not show any saving in power, but for speed reductions greater than 20 per cent brush-shifting shunt motors will show a material saving in power over wound-rotor motors with secondary resistance. Where special motors are designed for limited speed range, the per cent regulation at which it is economical to use the brush-shifting three-phase shunt motors is reduced.

An interesting application has been made in driving a triplex single-acting pump for a city pumping station. A special control panel incorporating a Ruggles-Klingemann regulator has been used to hold practically constant pressure in the mains with variable demand. As the pressure rises the speed of the motor is reduced and if it continues to rise the motor is automatically shut down, starting again automatically when the pressure drops to a predetermined value. When the pressure drops, the speed of the motor is automatically increased within the speed range of the motor.

Machine Tools

In most machine tool applications the motor is at a disadvantage because it is inherently a constant-torque motor, and for this service constant horsepower motors are usually necessary. For constant horsepower applications the size of the motor is determined by the horsepower requirements at low speed and thus with this type of motor the horsepower available at higher speeds is more than sufficient for the service. The motor may be used for machine tool service but, because of the constant-horsepower requirement, it is unnecessarily large and expensive.

Recently one of the motors has been applied to a press where the inherent regulation of the motor is being taken advantage of for flywheel effect.

Miscellaneous Applications

In addition to the uses previously mentioned the motors have been applied to newspaper presses, some paper machines, paper winders, waxing machines, linoleum calenders, and dough mixers.

A Study of Crystal Structure and Its Applications

PART IV*

THE BRAGG METHOD OF CRYSTAL ANALYSIS

By W. P. DAVEY

RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY

In our February issue, Dr. Davey devoted Part III of his series on Crystal Structure to a discussion of the Laue method of crystal analysis, wherein "white" x-rays are used to obtain the necessary experimental data. In Part IV, the author takes up the Bragg method, which employs x-rays of a single wavelength, obtained by the use of special filters. The theory of the Bragg method is discussed in this installment and in the next the author will give some illustrations of its use in determining the structure of crystals.—EDITOR.

We have seen how, in the Laue method of crystal analysis, the chain of evidence leading to the structure of a crystal is furnished mainly by the symmetry characteristics of the crystal, x-ray diffraction being used only to supply those links which would otherwise be missing from that chain. In other words, the Laue method makes x-ray diffraction play only the role of an assistant to the older crystallographic methods. In the Bragg method(1) emphasis is placed on the x-ray diffraction data, and symmetry considerations are used to supplement these data. The Bragg method of crystal analysis uses a single crystal. X-rays of known wavelengths are used so that from the angles of diffraction the corresponding interplanar spacings may be calculated at once from equation (1). These interplanar spacings together with the relative intensities of different orders of the diffracted beams constitute the x-ray data used by the Bragg method in determining the structure of the crystal.

Experimental Technique of the Bragg Method

The x-ray tube is operated at such a voltage as to produce a large proportion of characteristic rays from the anode (see Fig. 12). This bundle of characteristic rays contains more than one wavelength—for instance the *K* spectrum of Mo contains the following four wavelengths(11), $\alpha_1 = 0.7121$A, $\alpha_2 = 0.7078$A, $\beta = 0.6311$A, $\gamma = 0.6197$A. In some cases the beam may be made nearly monochromatic by means of filters. For example, the β and γ lines of the *K* spectrum of Mo may be almost completely absorbed by Zr which is especially transparent to the α doublet of $\mathrm{Mo_K}$.(23) The characteristic rays most used in the Bragg method are those of Fe, Cu, Mo and Rh. The proper filters are respectively Mn, Ni, Zr, and Ru. Fe and Cu possess the advantage of giving large angles of diffraction because of their long wavelengths, but the rays have such small penetrating ability that the x-ray tube must have a special window of Al foil or of thin mica to let out the rays. This window is fastened to the glass of the x-ray tube with sealing wax so that the tube can only be operated on the pump. Mo and Rh are free from this objection. Of these two Mo is most used because of the relative abundance of Zr for filtering material. Since absorption of x-rays is essentially an atomic property, it is easiest to use the Zr in the form of a compound with some atom or atoms of low atomic number such as ZrO_2, $ZrSiO_4$, $Zr(NO_3)_4$, etc. Experience shows that 0.036 grams of Zr atoms per square centimeter is sufficient to reduce the "white" rays and the β and γ lines of $\mathrm{Mo_K}$ to a negligible amount when the x-ray tube is operated at a voltage of 30 kv. r.m.s. or less. In this way the x-ray beam is composed mainly of the α_1 and α_2 lines.

It is essential to the fullest success of the Bragg method that the intensities of the diffracted beams be measured with a fair degree of accuracy. For this reason the ionization chamber is preferred to the photographic film as a means of detecting and measuring the x-rays.

The ionization chamber may be a metal tube filled with air, in which an insulated electrode inside runs parallel to the axis of the tube, but at some distance from it. Or the chamber may be a glass tube with two electrodes. The gas may then be C_2H_5Br or CH_3I. In such a case the insulation is

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*References made to material hitherto published in this series of articles may be readily located from the following table:

Issue	Figs.	Equations	Tables	Footnotes
Part I, Nov., 1924; p. 742	1 and 2	1 to 16	I and II	1 to 21
Part II, Dec., 1924; p. 795	3 to 10	17 to 32	III	22 to 27
Part III, Feb., 1925; p. 129	11 to 22	33 to 37	IV	28 to 42

preferably of quartz to prevent corrosion by the gas, and the port of entry for the x-rays is rendered gas tight by a thin mica or aluminum window fastened in place with sealing wax. The ionization current is measured by either an electroscope or an electrometer in the usual way, care being taken that the voltage between the electrodes is sufficient to catch every ion that is produced.

The crystal is mounted as in Fig. 23 so that any face may be oriented so as to lie in the plane of a beam of practically monochromatic x-rays. The mounting as a whole rests on a table which may be rotated about a vertical axis which lies in the path of the x-ray beam. The crystal and its mounting are so adjusted that this axis of rotation passes through a zone-axis(43) of the crystal. The advantage of this is that diffraction can then be obtained from each of several atomic planes by merely rotating the crystal table as a whole. The more important the zone-axis, the greater is this advantage. Usually a zone-axis is easy to find, for it may be located from two or more natural faces of the crystal. If only one natural face is developed in the crystal, the second atomic plane (corresponding to a second face) must be found by means of its diffracted x-ray beam, using cut-and-try methods.

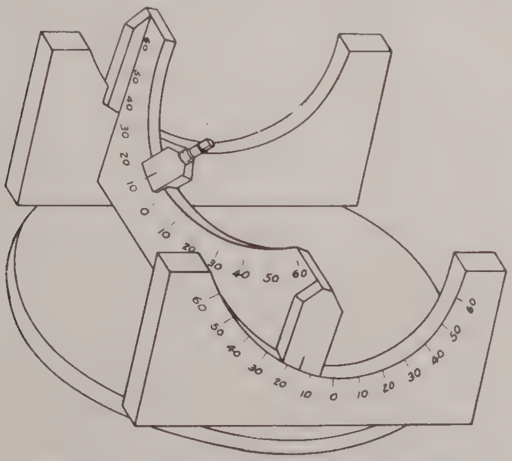

Fig. 23. Crystal Holder for Use with the Bragg Method of Crystal Analysis

Only a small crystal is required. In most cases the face of the crystal itself limits the x-ray beam sufficiently, so that the slits may be opened up to any reasonable width. If the crystal is in the form of a thin flake or a needle, Bragg(1) recommends that the beam be narrowed by means of the slit S_2, Fig 24.

The arrangement of the apparatus is shown in Fig. 24. The x-ray beam is defined by the two slits S_1 and S_2. These slits are usually made of lead or gold. The slit S_3 is made wide enough, so that it is not grazed by the main beam, but narrow enough to intercept any rays diffracted by the crystals in S_2. A slit S_4 in front of the ionization chamber, I, insures that only one diffracted beam enters the chamber at once. The filtering material is placed next to S_4, so that it not only filters out undesirable wavelengths coming directly from the x-ray tube, but also tends to filter out any secondary characteristic rays from the crystal under examination.

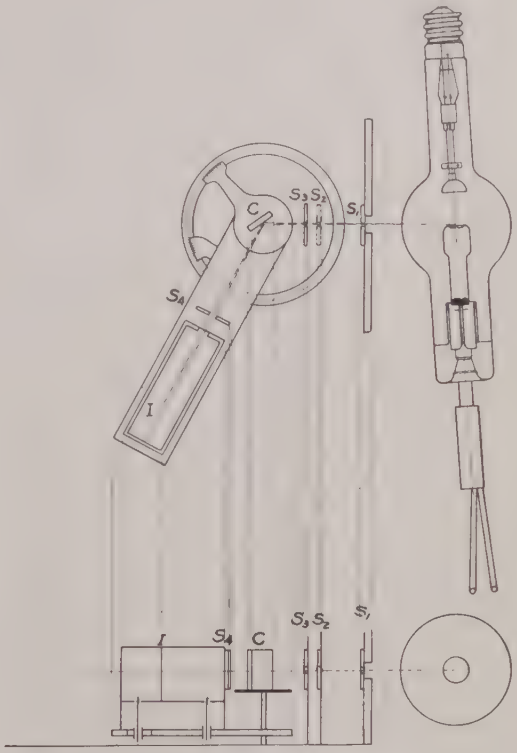

Fig. 24. Diagram of Bragg Apparatus

It is a matter of experience that few crystals will diffract Mo characteristic rays at angles of less than 3 deg. The crystal face is therefore set at an angle of about 3 deg. to the primary x-ray beam and the slit S_4 is opened up as wide as possible. The ionization chamber is slowly turned from an angle of about 6 deg. to an angle of 12 deg. or more. If some atomic plane which passes through the chosen zone-axis happens to lie at the correct angle to the x-ray beam, a diffracted beam will be found. Otherwise the table on which the crystal is mounted is turned slightly and the ionizing chamber is again slowly swept past. This is repeated if necessary until some plane is found which is so oriented as to show first order diffraction of the wavelength of x-rays employed in the primary beam. The slit S_4 is then narrowed down so as to be at least as narrow as the x-ray beam, and the ionization chamber is moved past, step by step. At each step a reading of the ionization current is made. The angle is noted at which the maximum ionization current is found. The crystal is then rotated 180 deg. and the angle of maximum ionization current is again noted. Half way between these two positions is the correct zero through which the undeviated beam passes after barely grazing the axis of rotation of the crystal. Half the angular distance between the two ionization maxima is therefore the angular deviation of the x-ray beam; it is the angle ϕ of equation (3) or twice the angle θ of equation (1). It is twice the grazing angle of incidence of the x-ray beam on the atomic plane in the crystal.

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(43) The line of intersection of two or more atomic planes is a zone-axis. The greater the number of intersecting planes the more important is the zone-axis.

Interpretation of the Diffraction Pattern

From equation (1) the interplanar spacing d is calculated, and parallel lines such as *ABC*, *DEF*, *GHI*, etc., of Fig. 25 are drawn to scale to represent the atomic planes which produce the diffracted beam. The crystal is then turned through an angle ψ such that another family of planes shows first order diffraction of the x-ray beam, and the interplanar spacing d' is calculated. A new set of parallel lines such as *AP*, *BQ*, *CR*, etc., of Fig. 25 are now drawn to scale so as to make an angle ψ with the first set of lines. Then the intersections of these lines represent possible positions for atoms in the crystal. The plot suggests other angles at which the crystal may be set in order to find first order diffracted beams. The interplanar distances found at these angles are then drawn on the plot, for example *AEI*, *GKO*, *MQ*, of Fig. 25. These interplanar distances will be multiples or submultiples of the distances predicted by the plot. This helps to determine the projection of the atomic arrangement in the plane of the plot, for now atoms are in general to be expected only at positions corresponding to the points where three lines intersect. The greater the number of planes examined which pass through the given zone-axis, the greater is the certainty with which the projection of the crystal lattice may be drawn. A similar procedure for some other zone-axis gives a second plot whose plane is at a known angle to that of the first plot. Knowing from these two plots the projection of the atomic positions on two intersecting planes, the positions of the various atoms in space are known.

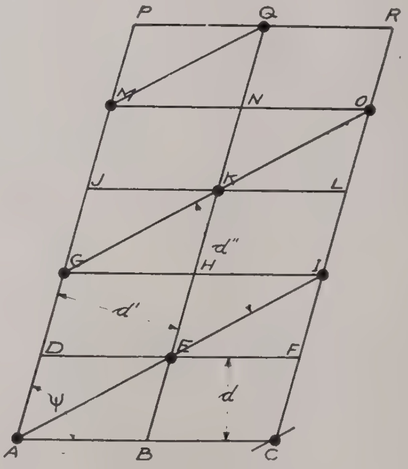

Fig. 25. A Bragg Plot

In some cases at least, the certainty of the positions assigned on the plot to the atoms may be greatly increased by considering the intensities of the different orders of diffraction for each of the planes. These intensities may be most accurately compared by making special measurements for the purpose.(44) (45) The ionization chamber is set at the correct angle to receive the first order diffraction from some family of planes as determined by the procedure outlined above. The slit S_4 (Fig. 24) is then opened up so that the opening is considerably wider than the width of the diffracted beam, and the crystal is swept past the diffracting angle at a uniform rate. The total amount of ionization produced in the chamber is taken as a measure of the intensity of the diffracted beam. The ionization chamber is then set at twice the angle and the crystal is again swept past the diffracting angle at the same rate as before, and the total ionization is again read. This is repeated for such other orders as may be desired. If a crystal is warped, one portion of a family of planes will make a slightly different angle with the incident beam from some other portion, so that there will appear to be more than one correct setting of the crystal for each family of planes. The procedure just given has the advantage that it frees the final result from this effect. There will still be present, however, errors caused by absorption, temperature changes, and the dimensions of the crystal. These are usually of relatively small importance in the interpretation of the structure of the crystal, and they will therefore not be discussed further at this point.

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(44) C. G. Darwin, *Phil. Mag.* *43*, 800 (1922).

(45) A. H. Compton, *Phys. Rev.* *9*, 29; *10*, 95 (1917).

If all the atoms in the crystal have equal diffracting power, and if they are arranged according to some elementary lattice (simple cubic, simple triangular, simple tetragonal, etc.) then every intersection on the plot will be the projection of the position of some atom in the crystal, and each order of diffraction will be less intense than the next lower order. For instance, the atoms of K and Cl are arranged on a simple cubic lattice and their atomic numbers are so nearly equal that they have nearly identical diffracting powers. The first order diffracted beam is more intense than the second order; the second order is more intense than the third order, etc. The normal rate of decline of intensity with increasing order of diffraction is given by W. L. Bragg(1)(46) for such cases as approximately

First order : second order : third order = 100 : 20 : 7. This has since been given(1) as

First order : second order : third order = 100 : 18.7 : 6.25.

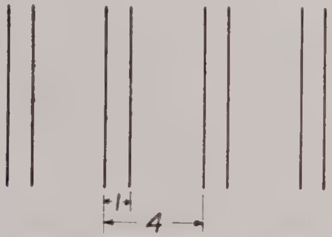

Fig. 26. Spacing of 1 1 1 Planes in Diamond

Extreme accuracy in the measurement of these intensities is rarely necessary because the intensities vary so markedly with changes in the type of crystal structure. For most work the essential point is to determine whether or not some one order of diffraction is entirely absent, or, if all the orders of diffraction are present up to the limit of the crystal and the wavelength of the x-rays, to know which of two orders of diffraction is more intense and to determine to within a few per cent what their relative intensities are. If the structure is more complicated, the intensities of successive orders of diffraction do not decrease regularly. For instance, even though all the atoms in diamond (see Figs. 7 and 8) are of the same element and may therefore be supposed to have the same diffracting power, the second order diffraction from the 1 1 1 planes is missing, although the third and fourth orders are present. This is interpreted as meaning that the 1 1 1 planes are arranged in pairs (see the discussion of the diamond cubic lattice in Part II) such that the distance between the members of a pair is one fourth the distance between corresponding planes in two adjacent pairs. If, therefore, a diamond is oriented so that the zone-axis under investigation lies in the 1 1 1 plane, then the lines in the plot for this family of planes would have to be spaced as in Fig. 26.

The general method of interpreting the data on the intensities of various orders of diffraction from a single family of planes is as follows. An arrangement of atomic planes is assumed and the relative intensities of the different orders of diffraction are calculated in terms of the amplitudes and phase relationships of the waves from the different planes of the family. The calculated intensities are compared with those found by experiment, and, if necessary, the procedure is repeated until a marshalling of planes is found such that the calculated and experimental results are sufficiently in agreement.

In order to illustrate one method of making these calculations let us suppose that the crystal is composed of equal numbers of each of two kinds of atoms A and B whose atomic numbers are N_A and N_B respectively, and let the atomic planes under consideration have a spacing d as calculated from the diffraction pattern. Two possibilities are open. Either (1) each plane in the family contains both A and B and these planes are spaced a distance of d apart (see Fig. 27), or (2) there are alternate planes of A and of B so spaced that the A-planes are a distance of d apart from each other and the B-planes are a distance d from each other, while A and B are spaced a distance apart $\frac{1}{m}d$ (see Fig. 28). In the first case the waves from the

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(46) W. L. Bragg, *Proc. Roy. Soc. A.* *89*, 468 (1914).

A-atoms and those from the *B*-atoms are necessarily in phase and the amplitude of the resultant wave is the sum of the amplitudes of the waves sent out by the two sets of atoms. These amplitudes must be linked up in some way with the atomic number. The Braggs⁽¹⁾ assume that, at least at small angles, the electrons in the atoms vibrate so nearly in phase with each other that the amplitude of each wavelet is proportional to the number of electrons in the atom which sends out the wavelet—i.e., to the atomic number. Since the ionization chamber measures intensities rather than amplitudes we must deal with the square of the resultant amplitudes. In terms of Bragg's assumption we must therefore consider the intensity of an x-ray beam diffracted from a plane containing both *A*- and *B*-atoms as being proportional to

$$I=(N_A+N_B)^2 \qquad (38)$$

In the second case the waves from the *A*- and *B*-planes are out of phase by an angle ω such that for the first order of diffraction

$$\frac{\omega_1}{2\pi}=\frac{\frac{1}{m}d}{d}=\frac{1}{m}$$

$$\text{for the second order, } \frac{\omega_2}{2\pi}=\frac{2}{m}$$

$$\text{for the third order, } \frac{\omega_3}{2\pi}=\frac{3}{m}$$

$$\text{Therefore}\quad \left.\begin{aligned}\omega_1&=\frac{2\pi}{m}\\ \omega_2&=\frac{4\pi}{m}\\ \omega_3&=\frac{6\pi}{m}\\ \omega_n&=\frac{2n\pi}{m}\end{aligned}\right\} \qquad (39)$$

In terms of the assumption mentioned above in which the amplitudes of the wavelets are taken to be proportional to the atomic numbers, the vector sum of the amplitudes of the wavelets from *A* and *B* is proportional to

$$(N^2_A+2N_A\,N_B\cos\omega+N^2_B)^{1/2}$$

thus giving a resultant wave whose intensity is

$$I'=N^2_A+2N_A\,N_B\cos\omega+N^2_B \qquad (40)$$

Let the intensities of successive orders of diffraction for the first case be $I_1, I_2, I_3, \ldots$ Their ratios as experimentally determined by W. L. Bragg have already been given. The corresponding intensities $I'_1, I'_2, I'_3, \ldots$ for the second case will differ for every possible combination of values for N_A and N_B and for every possible value of $\frac{1}{m}$. They are easiest calculated in terms of I_1, I_2, I_3, ..., so that we have from equations (38), (39) and (40)

$$I'_n=I_n\,\frac{N^2_A+2N_AN_B\cos\frac{2\pi n}{m}+N^2_B}{(N_A+N_B)^2} \qquad (41)$$

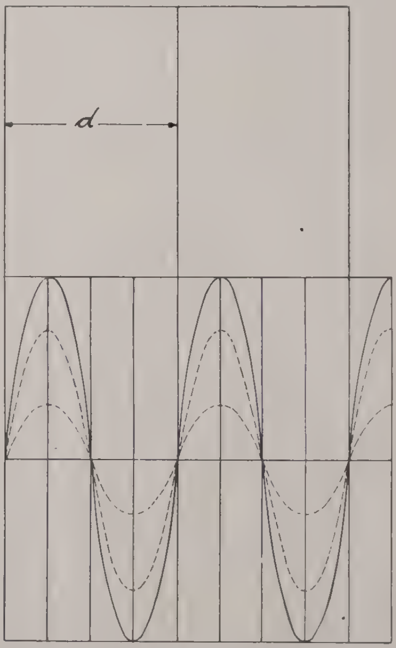

Fig. 27. Resultant Wave from Planes Each of which Contain Two Kinds of Atoms

If there are *p* atoms of *A* and *q* atoms of *B* in the chemical formula for the crystal, then N_A may have to be replaced by pN_A and N_B.

This line of reasoning has been applied by the Braggs to the case of the 1 0 0 planes of zincblende (ZnS) for which in equations (40) and (41) $N_{Zn}=30$, and $N_S=16$. It can be shown that ZnS has a diamond cubic structure. The Zn forms a face-centered cubic lattice like Fig. 5, and the S occupies the four inside positions shown in Fig. 6. This causes the 1 0 0 planes to be composed alternately of Zn and S. Let us assume first that each 1 0 0 plane contains both Zn and S. Then the ratio of the intensities of the first two orders of diffraction should correspond to the "normal rate of decline," i.e., $I_1 : I_2 = 100 : 18.7$. Experimentally they are in the ratio of 52 : 100. Obviously the assumed structure is incorrect. Let us now assume that the Zn and S lie in alternate planes. Equation (41) does not lend itself readily to a direct solution for $\frac{1}{m}$, but various values of $\frac{1}{m}$ may be tried in the equation until one is found which gives the experimental intensities. Suppose that the value on trial for $\frac{1}{m}$ is 0.50. Then for the first order, n of equation (41) is 1 and

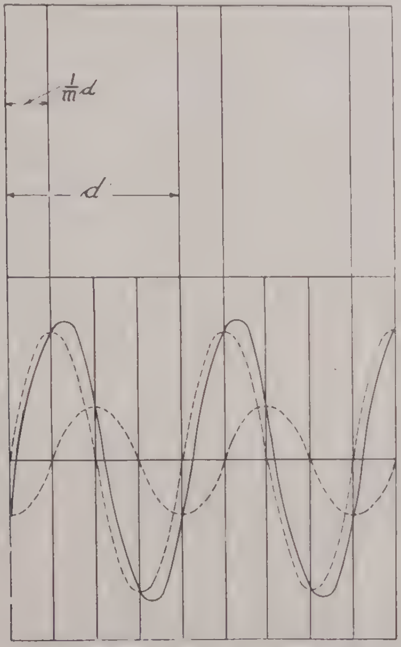

Fig. 28. Resultant Wave from Planes of One Kind of Atoms Alternating with Planes of Another Kind of Atom

$$I'_1 = I_1 \frac{(30-16)^2}{(30+16^2)} = 0.0926 I_1$$

For the second order $n = 2$ and

$$I'_2 = I_2 \frac{(30+16)^2}{(30+16)^2} = I_2$$

Therefore

$$\frac{I'_1}{I'_2} = 0.0926 \frac{I_1}{I_2}$$

But by experiment

$$\frac{I_1}{I_2} = \frac{100}{18.7}$$

Therefore

$$\frac{I'_1}{I'_2} = 0.0926 \frac{100}{18.7} = \frac{49.5}{100}$$

which agrees very well with the experimental ratio of 52 : 100.

After the order of magnitude of $\frac{1}{m}$ once has been determined by this method, a more exact value may often be decided upon in terms of the symmetry characteristics of the crystal. For instance, a still closer check with experiment for ZnS may be had by taking $\frac{1}{m}$ as 0.48 or 0.52, but the symmetry of the crystal is such that we must accept 0.50 as the correct value.

W. H. Bragg has given some interesting evidence[47] which goes to show the correctness of his assumption that at small angles the amplitude of the diffracted beam is proportional to the first power of the atomic number. The structure of calcite ($CaCO_3$) has been worked out[46] from its x-ray diffraction pattern supplemented by symmetry considerations. It is a simple rhombohedral lattice with Ca^{++} and CO_3^{--} at alternate corners of the rhombohedron. This structure has since been confirmed[28] by the Laue method. The interplanar spacing of the 1 1 1 planes (referred to trigonal axes) is just double that of the $\bar{2}$ 1 1 planes. The second order diffracted beam of 1 1 1 therefore falls at the same angle as the first order beam from 2 1 1 , so that their intensities may be compared without any error due to angle. The 1 1 1 planes occur in alternate layers of Ca^{++} and CO_3^{--}. In the second order their effects are additive so Bragg assigns a diffracting power equal to the mass of $CaCO_3 = 40+12+48 = 100$. The $\bar{2}$ 1 1 planes are composed $Ca+C+O(=68)$ with other planes of O lying between them. The effect of those O planes is considered to be negligible. The ratio of the masses of the two planes is 100 : 68. The ratio of intensities from experiment is 100 : 66. If we consider the ionic numbers rather than the atomic weights so as to fit in with our previous discussion, we obtain practically the same results. $Ca^{++} = 18$, $CO_3^{--} = 2+3\times 10 = 32$, giving a value of 50 for the second order beam from 1 1 1. $Ca^{++} = 18$, $CO = 2+10 = 12$, giving a value of 30 for the first order of $\bar{2}$ 1 1 . These are in the ratio of 100 : 60 which probably agrees with the experimental ratio to within the accuracy of the data.

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(47) W. H. Bragg, *Trans. Roy. Soc. A*, *215*, 253 (1915).

In some cases the agreement between theory and experiment is not so satisfactory as those just cited. For instance, all methods of crystal analysis agree in assigning to NaCl a simple cubic structure (Fig. 3) with Na and Cl at alternate corners of the simple cube. This structure gives 1 1 1 planes of two kinds, one containing only Na, the other containing only Cl, and it is inherent in the simple cubic structure that these are equally spaced—i.e., $\frac{1}{m}=0.50$. If now the intensities for the first order and second order of diffraction from the 1 1 1 planes of NaCl are calculated by the method outlined above, we obtain

$$I'_1 : I'_2 = 24.5 : 100$$

Experimentally Bragg finds(1) a ratio of 16.5: 24.4 = 67.6 : 100. It is not at all certain that the excellent agreement between the calculated and experimental intensities for zincblende is anything more than accident. There seems to be every reason to believe that both ZnS and NaCl are composed of ions rather than atoms. This will be discussed more fully in a later chapter. It will be sufficient to state here that such a viewpoint is consistent with all the known properties of such compounds and with their crystal structures. If this viewpoint is correct, we should not have used the atomic number 30 for Zn but the ionic number 28 for Zn^{++}; we should not have used 16 for S but 18 for S^{--}. Using these ionic numbers in equation (41) we find

$$I'_1 : I'_2 = 25.3 : 100$$

instead of the experimental 52 : 100. In the case of NaCl we find 43.7 : 100 instead of the experimental 67.6 : 100. This disagreement between the calculated and experimental intensities might easily be explained by the fact that equation (41) takes no account of changes in intensity caused by (a) absorption of x-rays in the crystal, (b) temperature, (c) size of the crystal, and (d) angle of diffraction. This is rendered all the more plausible by the fact(48) that under different experimental conditions the ratio for the first and second orders of diffraction from the 1 1 1 planes of NaCl was found to be 9.00: 33.1 = 27.2: 100 which is about as far below the calculated value as Bragg's is above it. Except for (d) equation (41) is no more unsatisfactory in these respects than the more cumbersome equation (37) given in the discussion of the Laue method. Except for the empirical proportionality factor $\left(\frac{d}{n}\right)^{2.35}$ mentioned in that discussion, the two equations rest on the same assumption, namely, that the amplitude of an x-ray beam diffracted by an atom is proportional to the first power of its atomic number.

The discrepancies which have been noted above are not so serious as they might seem at first sight. As has been mentioned before, it is often sufficient to know only that certain lines in the diffraction pattern are more intense than certain other lines. Equation (41) is, therefore, an exceedingly useful equation. The cumulative evidence of even relative intensities is of great weight, and if the lines are so chosen as to represent several orders of diffraction for every family of planes belonging to two or three important zone-axes, the chance of a false interpretation is very small indeed.

If the crystal contains only one kind of atoms (i.e., if it is a chemical element) then this equation is independent of any assumptions as to the effect of atomic number on the amplitude of the component wavelets. In such a case it gives a value of $\frac{1}{m}$ whose accuracy is limited chiefly by the accuracy (not reproducibility) of the intensity measurements of the different orders of diffraction and by the accuracy to which the intensity ratios are known for the simple structure. The value of $\frac{1}{m}$ so obtained will be very close to that required by some structure which is consistent with the symmetry characteristics of the crystal. It may in this way serve as a criterion between two structures which are equally consistent with the symmetry of the crystal. If the crystal contains two or more kinds of atoms (i.e., if it is a chemical compound) equation (41) is still useful, but not always to the same extent as in the case of an element. By expressing the fact that atoms of high atomic number diffract x-rays more strongly than atoms of low atomic number, it makes it possible to determine in most cases whether a family of planes is composed of planes which are all exactly alike or whether it is made up of alternate layers of A and B. It is evident from an inspection of the equation that if the crystal is composed of planes of A and of B it is difficult to distinguish between the composition of nearly equally spaced planes if the atomic numbers N_A and N_B are nearly equal. The equation is also insensitive if N_A is very large and N_B very small. In such cases, the Bragg plot gives no hint as to the complete solution of the crystal structure, for it tends to show only the positions of A. The exact determination of the location of B is therefore left in such cases to considerations of symmetry. As in the case of the Laue method, the Theory of Space Groups, especially as given by Wyckoff and by Astbury and Yardley,(37) is useful in this connection as a means of insuring that no possibilities have been overlooked. Considerations of electrostatic equilibrium, cleavage, and etch figures are sometimes valuable in helping to decide between alternative structures offered by the Theory of Space Groups.

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(48) W. L. Bragg, R. W. James, and C. H. Bosanquet, *Phil. Mag. 41*, 309 (1921).

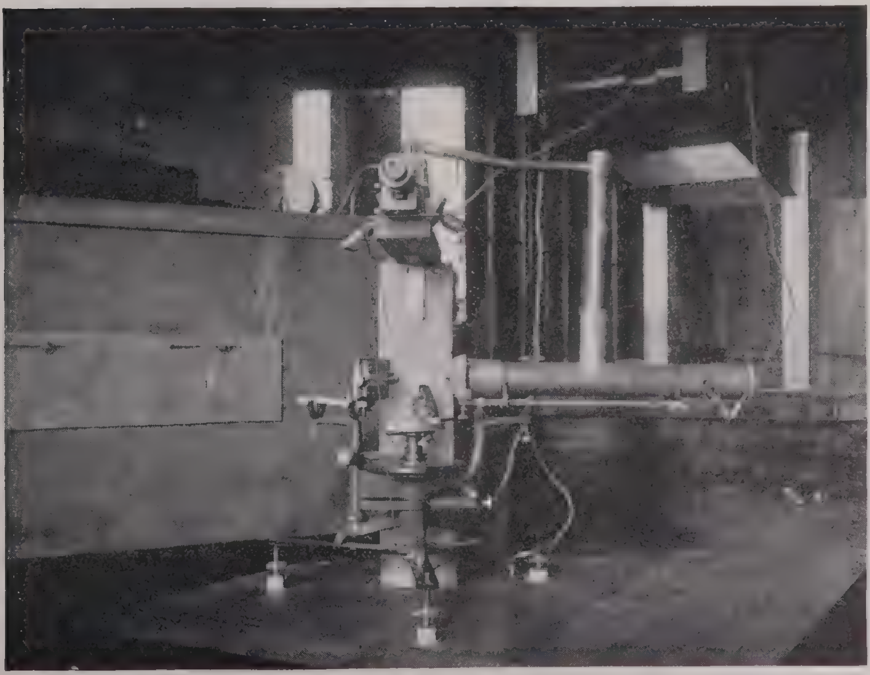
(To be continued)

ERRATA

Part I, Nov. 1924
- p. 743: Footnote (1); change 1915 to 1924.
- p. 744: Footnote (5); change 1923 to 1924.

Part II, Dec. 1924
- p. 799: Equation (25); the fraction ½ at the right-hand end of the expression is an exponent that applies to the entire right-hand side of the equation.
- p. 802: Equation (32); change ¾ to $\frac{\sqrt{3}}{4}$

Part III, Feb. 1925
- p. 130: The Fig. No. and title beneath the lower illustration in the first column should have appeared beneath the upper illustration in the second column and vice versa.
- p. 132: Fig. 16; the axis in the plane of the paper to the right from O is the X-axis. The axis perpendicular to the plane of the paper shown to the left of O is the Y-axis.
- p. 134: first column, 13th line; change "spors" to "spots."
- p. 137: first column; 13th line; change $\sqrt{h^2+k^2+l^2}$ to $\frac{1}{\sqrt{h^2+k^2+l^2}}$.



(Photo by courtesy of J. T. Norton)

Bragg Crystal Analysis Apparatus Made by the Department of Physics, Massachusetts Institute of Technology

New Fields for Radio Signalling

By E. F. W. Alexanderson

Chief Consulting Engineer, Radio Corporation of America

The American public prides itself on its scientific sophistication. With each new discovery we find people saying on every hand "Ah, modern science can do anything." It is a pity that such complacence should exist in the layman's mind, for certainly it is absent from the mind of the scientist. And thus, while millions the world over have grown to look upon radio as a well-known household pet, the men who have spent years developing radio communication realize that they are only at the threshold, and they gaze out into the future with the humility born of real knowledge.

The vista is particularly interesting as here described by Mr. Alexanderson, who delivered the early part of the article as an address last month before the A. I. E. E. at Cleveland, and has since for publication in our magazine added the detailed explanation of the scrambling and unscrambling of waves.—Editor.

Trans-oceanic communication has always been the force that developed and maintained great civilizations. In classical times the great commonwealth of the Mediterranean was held together by speedy ships communicating with Rome as a center. The modern commonwealth of the Atlantic Ocean has been held together by the telegraph cable system centered in London.

The scene is now shifting and New York is becoming the financial and commercial center of the world. New York has now a well developed new system of communication reaching all parts of the world by radio. It is the growth of this world system of radio communication which I wish to bring to your attention. The Radio Corporation of America started operation in 1920, and the system of communication has already outgrown the experimental stage and become a public service on a large scale. It is difficult to convey by words the appeal to the imagination which the development and operation of this world wide spider web of communication has to those engaged in it. We had to develop transmitting stations and antenna systems, high-frequency alternators with accurate speed control, high-speed modulation of the antenna current, high-frequency insulation withstanding voltages higher than those used in any power lines, etc. Atmospheric disturbances have been conquered by an antenna system capable of receiving all the different signals from all parts of the world, concentrating the operation of the whole system in one large room in New York.

The aims of the engineers responsible for this system are largely the same as those operating a railroad; reliability, service and speed. Such aims have already been realized, but this does not mean that the development of the radio technique with relation to communication has come to a standstill any more than that we have a right to say that the steam locomotive will not be replaced in time by an improved form of tractive power. It does mean, however, that one of those phases has been reached in radio communication which occurs in every engineering development, that the technique has, after a strenuous effort, caught up with the commercial requirements and is now enjoying a breathing spell, getting ready for new efforts. This stage was reached by the marine steam engine before it was replaced by the steam turbine. This stage has also been reached in electric power engineering. This is the period when the technical achievements of the past are capitalized and exploited. Technical development work is always done at a loss in the initial stages. If the engineering art did not have these breathing spells it could not proceed because in the first place the source of financial support would dry out, and in the second place the engineers would be tied down with details and would not have time for the fundamental research which paves the way for the next advance.

Radio broadcasting has also within the last year settled down to a public service and a profitable field for commercial exploitation. The technique has reached such a degree of perfection that the greater part of the public is interested in radio because of the artistic enjoyment, information and education which it renders rather than for the chances for experimentation and invention which it offers. There is, however, a large and growing group of amateurs who pursue radio for the love of the art, and the art to them is not the performance in the studio but the technical art of radio itself. Radio has enjoyed a greater following of amateurs than any other branch of engineering, and it is the thought of these amateurs that moulds the future. They are one step closer to reality than the imaginative writers, like Kipling and Jules Verne, who give us glimpses of the future long before they can be realized. The amateur likes to anticipate what advances in the art may reasonably be expected within the next decade.

When we try to anticipate the next substantial advance, we must first take account of what new knowledge we have acquired in the last few years which we hope to exploit. The present day radio communication utilizes long waves. The propagation characteristics of those long waves have been thoroughly explored and we know how much radiated energy is needed for communication over any distances day and night. We know how to build radio transmitters and antenna systems and we have learned how to control the effect of atmospheric disturbances under practically all conditions.

The long wave follows the surface of the earth and is subject to laws of attenuation which are by this time well understood. In the broadcast range of wavelengths, on the other hand, there is considerably more irregularity. Signals sometimes go through and sometimes not, depending upon phenomena which are not under our control. Sometimes extraordinary distances are covered with very low power.

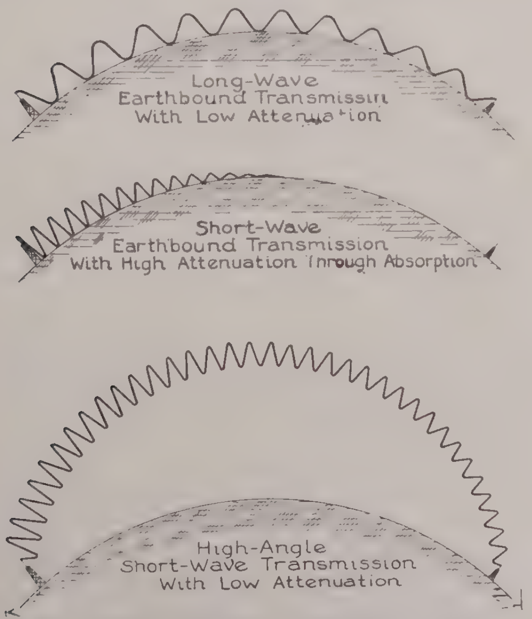


Fig. 1. Radio Transmission Characteristics of Long Earthbound Waves, Short Earthbound Waves and High-angle Short Waves

During the last year a number of long distance communication circuits have been introduced utilizing waves below 100 meters. Such circuits are now in operation between New York and Europe, New York and South America, and San Francisco and Hawaii. The adoption of short waves for communication over long distances is contrary to the earlier well established experience in which it has been found that, the longer the distance, the longer should be the wavelength for giving reliable service. There are many indications that we are in the short wave field dealing with phenomena of wave propagation quite different from those encountered in the past. This new field of knowledge is being explored and promises to open up new and unexpected fields in radio.

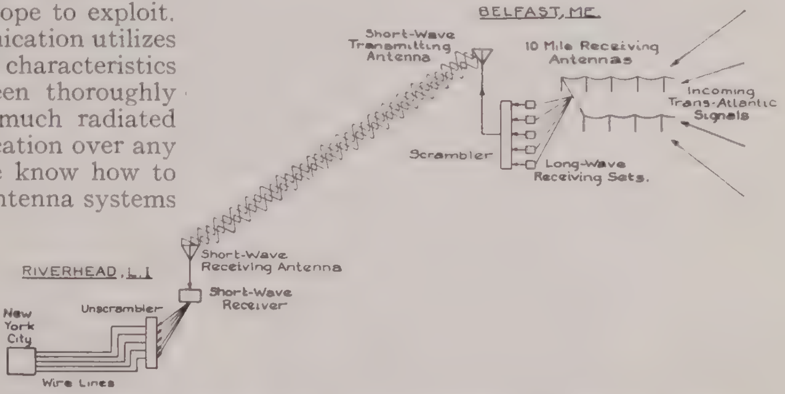

BELFAST, ME.
Short-Wave Transmitting Antenna
10 Mile Receiving Antennas
Incoming Trans-Atlantic Signals
Scrambler
Long-Wave Receiving Sets.
Short-Wave Receiving Antenna
RIVERHEAD, L.I.
Short-Wave Receiver
Unscrambler
New York City
Wire Lines

Fig. 2. Graphic Diagram Showing the Re-transmission of Trans-Atlantic Signals Through Belfast, Me., to Riverhead, L. I., by Means of Scrambled Waves

The short waves do not follow the surface of the earth and we have learned to launch the wave into space like high angle gun fire, in such a way that it travels in the upper atmosphere and comes back to earth a great distance away. By travelling on this upper track, the waves are not subject to the ordinary laws of absorption. So long as we are working with earth-bound waves we must use long waves for long distances because the earth absorption of the long waves is comparatively small. When, on the other hand, we use high angle radiation with short waves we utilize a different form of wave propagation. These new tracks in the ether are being explored by systematic research work as well as by commercial communication.

Thus a new phenomenon or law of nature has been established though we are not yet able to give an adequate explanation of it.

The old theory of the Heaviside layer as a conducting and reflecting surface does not fit the phenomena as observed, but there is a more promising theory recently advanced by Sir Joseph Lamor explaining the curvature of the wave by a change in the refractive index of space caused by the presence of electrons in the upper atmosphere.

It has taken many years to master the technique of the earth-bound waves so that we can now count on continuous and reliable communication. The curved space radiation with short waves will undoubtedly open up new and important fields for radio. We are utilizing it already in commercial traffic but it will probably be many years more before this is as thoroughly understood and mastered as the long-wave technique.

The short wavelengths open up not only new paths for wave propagation but give us an almost inexhaustible scale of wavelengths, provided that we utilize it to full advantage. The following facts will make this clear. Almost all the trans-oceanic telegraph stations in the world are crowded into a wavelength band 10,000 cycles wide. This space in the ether is utilized nearly up to its ultimate capacity. But the short-wave field below 100 meters includes ten million cycles; thus there is room for 1000 times as many messages as are now being handled by all the long-wave stations put together, and those stations are at present capable of carrying all the trans-atlantic and trans-pacific telegraph traffic of the world. To carry 1000 times as many messages would seem fantastic, but attempts of stating our dreams of the future in terms of the cold facts of today always lead to absurdities.

As a matter of fact we would not have 1000 times as many messages and if we did, they would be of a very different character. But we have a new tool to do things with, and we must use our imagination as to what to do with it.

Two years ago Mr. Owen D. Young, Chairman of the Board of Directors of the Radio Corporation, stated his conception of what radio ought to accomplish. He wished to press a key and—zip—a whole page of a newspaper would be flashed across the ocean. Acting upon this lead, we went ahead to see what could be done and in less than two years we had demonstrated picture transmission across the ocean. There is a long way between the transmission of a picture and the flashing of a whole newspaper but the art is rapidly moving in that direction.

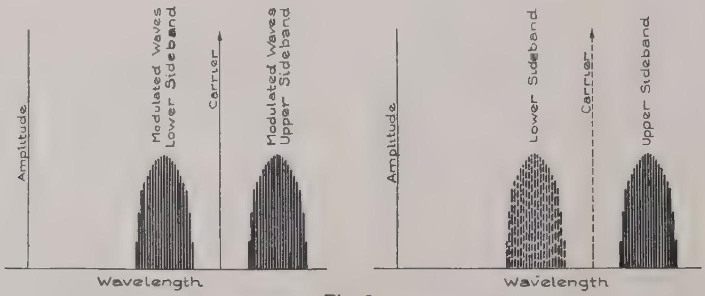


Fig. 3

Simple Telephonic Modulation. The carrier and both side-bands are radiated

Phantom Carrier. The carrier wave and lower modulation side-band are suppressed

Scrambled Messages

An inspiring thought is always many years ahead of the event it contemplates. As an illustration of this, I wish to mention an important advance in radio which was conceived of long ago and has now been realized. In 1912, I visited the laboratory of Mr. John Hays Hammond, Jr., to make tests on two alternators of 100,000 cycles which he had purchased and installed, and we had some, to me, very inspiring conversations. We discussed the modulation of the antenna current, trans-atlantic telegraphy and telephony, control of airplanes and submarines, and Mr. Hammond outlined his idea of taking a variety of messages and scrambling them together, superimposing them on one transmitter and sending them forth by radio as a composite message, and then again unscrambling them into separate messages.

Now after twelve years, we find a paper presented to the Institute of Radio Engineers by Beverage, Hansell and Dean which tells just how this is done and explains the theory of the apparatus and its operation.

This is what happened in the meantime. The fight against atmospheric disturbances and static has led us to build on Long Island a central receiving station with an aerial system consisting of two antennas, ten miles long, joined by a transmission line. This seems like a large equipment but its cost is insignificant in comparison with the service it renders. This antenna system known as the Beverage-Rice system eliminates practically all the static and intercepts on one antenna all the signals from all the stations in Europe. These signals are then automatically separated in more than a dozen receiving sets and sent over wire lines to the operating room in New York.

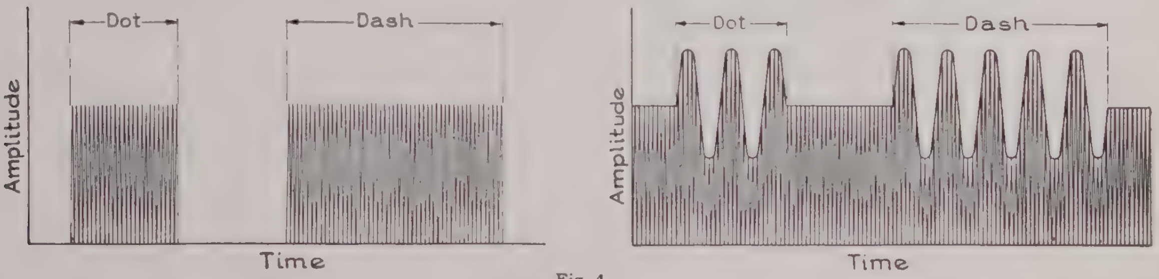


Fig. 4

Simple Continuous Wave Telegraph Signal

Telegraphic Signal Transmitted with Short-wave Carrier and Long-wave Modulation

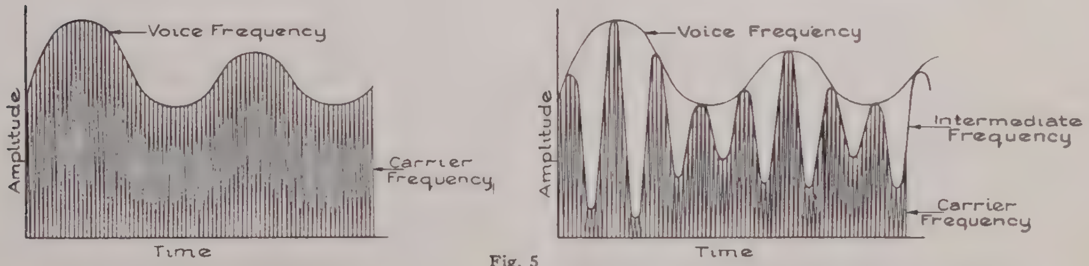


Fig. 5

Simple Telephonic Modulation

Telephonic Transmission with Double Modulation, that is, Short-wave Radio Carrier and Intermediate Long-wave Carrier

There is only one kind of disturbance that this system does not practically eliminate, and that is a thunder storm in the neighborhood of the station directly on the line from which the signals come. To insure service even in this contingency, a similar large antenna system was built at Belfast, Maine, which would be immune to a thunder storm on Long Island, while the Long Island station would have a similar immunity to conditions in Maine. But the problem was, how to get the signal down from Maine to Long Island. The authors of this recent paper show how by much painstaking work and many ingenious new inventions this has been done, thereby realizing Hammond's dreams of years ago. The signals from Europe are picked out of the ether in Maine, scrambled together and sent out by a single transmitter. This composite signal is then received on Long Island and unscrambled into a dozen signals which are fed into the long-wave receiving sets where they go through the usual process of detection and transmission to New York. The signals so reproduced are exact replicas of the original signals, so that the operators in New York do not know whether they have received the original signals, or the scrambled and unscrambled signals via Belfast, Maine.

Those who wish to thoroughly understand the process of scrambling and unscrambling of waves are referred to the paper by Beverage, Hansell and Dean. The principle is simple enough after it is well understood but the subject can be grasped only by building up a mental picture in several steps.

Ordinary broadcasting is a transmission of a single message on a single carrier wave. This carrier wave is accompanied by two sets of modulation waves, one of a higher frequency, the other of a lower frequency than the carrier wave. The frequency of the modulation waves differs from the frequency of the carrier wave to the exact extent of the tone pitch of the modulation. It is not necessary to radiate both the upper and the lower sets of modulation waves because one of the modulation waves will, by beat effect against the carrier, reproduce the signal. Ordinarily the antenna is slightly detuned from the carrier so as to favor one of the modulation waves.

There is another method of transmitting radio telephony which consists in filtering out the carrier wave as well as one of the two modulation waves and radiating the remaining modulation wave. This method is sometimes designated as suppressed carrier and sometimes as side band radiation. It may properly be called the "phantom carrier." The advantage of this method of radiation is that it saves radiating power and saves the wavelength space that would have been occupied by the suppressed carrier and the suppressed modulation wave. The phantom carrier is made real again in the receiving set by a heterodyne oscillator and combines with the modulation wave received through the ether, thereby creating beat notes which reproduce the voice or musical modulation used in the transmitting station. For the sake of brevity we will characterize this system as transmission by phantom carrier.

A departure in a different direction was the Hammond system of double carrier or double modulation. This system uses an intermediate long-wave carrier frequency upon which the signal is superimposed by modulation. Then the long-wave carrier frequency is again superimposed as modulation frequency upon a short-wave carrier which is actually radiated. A message may thus be transmitted through a process of double modulation, the advantage of which is a high degree of selectivity and freedom from interference. This high selectivity is attained in a way analogous to the superheterodyne receiver, though the intermediate frequency is introduced at the transmitting station.

Mr. Hammond went still further by introducing a multiplicity of intermediate long-wave carrier frequencies each conveying a separate signal. The several carrier waves so modulated are combined and used as a modulation frequency for a single short-wave carrier.

In the Belfast-Riverhead system, Beverage, Hansell and Dean have gone still further by applying the principle of phantom carrier transmission to the intermediate frequency of the Hammond multiplex double modulation system.

The process of unscrambling consists in using a short wave detector which resolves the composite radiation into a multiplicity of long-wave signals. All the long-wave signals so produced are impressed upon a bank of long-wave receivers, each of which picks out its own message by the usual process of tuning and detection. This method of signaling by double carrier has the advantage of much greater utilization of the available wavelength channels in the ether.

If, for instance, it is desired to convey a number of messages of the type of transoceanic telegraph signals, the waves may be spaced 300 cycles apart. Ten such signals when arranged to best advantage may then be confined within a wavelength band 3000 cycles wide. When the double modulation system with phantom carriers is used, such signals may be conveyed by ten intermediate long-wave carriers, all confined to a wavelength group 3000 cycles wide. Let us furthermore assume that the short-wave carrier is 100 meters or three million cycles. We thus find that a waveband carrying the ten telegraphic signals may occupy only 3000 cycles out of a 3,000,000-cycle carrier wave, that is, a waveband only one-tenth of one per cent wide.

Isocandles and the Asymmetric Lighting Unit

By Frank Benford

Physicist, Illuminating Engineering Laboratory, General Electric Company

The usual method of plotting photometric data has been found to be inadequate for representing the light distribution from unsymmetrical or asymmetric lighting units. Because of this fact and the coming popularity of these units for suitable purposes, the author has developed a method of plotting their distribution of intensity so as to give a complete engineering description on a single curve sheet. A new word "isocandle" has been coined to aid in this matter, and a type of web has been adopted to permit a fairly accurate representation of a spherical surface. On this spherical surface which is of course flattened out so that it can be printed on a page, the intensities of radiation are plotted as continuous closed lines, giving in general a chart like a topographic map of a hilly country. A mere glance at one of these diagrams gives a good idea of the nature of the unit, and in this respect the method is a considerable improvement over the older methods that required from nine to eighteen curves, often on separate sheets, to give less engineering information.—Editor.

Symmetric or One-plane Units

A great majority of all lighting units give a distribution of light that is symmetrical with respect to a vertical axis. The symmetry is not perfect, however, for small variations occur due to the form of the filament or the momentary condition of the arc, and to the inevitable variations in the various reflectors and globes that go to make up the unit. It is the practice in laboratories where accurate data is the aim to find the distribution of light in two or more vertical planes; but unless the variations from side to side are pronounced and of a definite character, it is customary to take an average of the several planes and issue a curve of "average distribution of light in a vertical plane." It is only by this method that it is possible to compare different units accurately, or even the same unit with different lamps, for it is often the case that the variation from side to side in a given unit is as great as the variation introduced by making some change in the unit itself, say by the introduction of a small internal reflector. It thus happens that the data of the "average plane" should have a better accuracy than can be expected from a plane selected at random and the word "average" should therefore indicate that the given data are photometric averages from a photometric exploration much more extended than the word plane might imply.

Having properly determined the "average plane" data, this plane may be set at any angle provided it is kept in correct axial relation with the unit, In computing illumination along a line that does not pass through the axis of the unit, it is easy to consider the average plane as being rotated on its axis to bring it in line with the various points on the line of illumination. For purposes of presentation, the actual distribution of light (which could properly be represented by an irregular surface of revolution formed about the unit) is now represented by a line which can be rotated about the axis. Instead of a drawing in three dimensions corresponding to the surface of revolution, the drawing can now be made in two dimensions, and thus represents a great simplification without a serious loss in the graphic or picture value of the drawing.

Asymmetric or Multi-plane Units

The desire for higher illumination levels on street or highway for a given wattage has led to the design of a number of units that have a marked asymmetry in their distribution of light. Thus in the illumination of a highway the road surface and the ditches are all that need be considered, and the side light that in the city is so useful for lighting up the lawns and buildings may here be directed onto the road. When this is done the photometric data lose the simplicity that goes with the single "average plane," and a complete presentation of the characteristics of the unit require a number of planes. In the past it has been customary to test the unit in the vertical planes that contain the greatest intensity of radiation (Fig. 1), and also perhaps, in a cone around the unit, selecting the conical angle so that the peak of intensity is again included (Fig. 2). These two explorations tell much about the unit but they leave much more untold. Nothing is more aggravating than to locate and explore in this manner the two beams of a highway unit and then have someone ask: "What is the illumination along the fence line?" The question cannot be answered, and no general question can indeed be answered from the data of the curves. The vertical plane passing through either of the peaks of intensity or beams does not coincide with the ditches, with the edge of the road, with the centerline or any other line in which we are usually interested. The "maximum plane" is here an isolated fact that is difficult to transform into road illumination, and further engineering analysis is quite thoroughly blocked.

The complete photometric analysis of an asymmetric unit, using the word "asymmetric" to indicate any distribution that is not uniform in a given zone around the axis, requires testing in a number of vertical planes, and as a rule 36 planes spaced 10 deg. apart are required. These planes each include 180 deg. of elevation or from the nadir to the zenith. A few units have different distributions in each of the 36 planes; a larger number of units are symmetrical in planes equally distant from a central plane. The highway reflector is an example of this latter type. Two beams at an elevation of 81 deg. and separated by 180 deg. contain the greater part of the light. The plane of symmetry in this case crosses the road at right angles and planes equally spaced to either side give equal distributions. Nine planes 10 deg. apart starting from the plane across the road and extending around to the plane parallel to the edge of the road will give a complete photometric presentation of the unit. In such a photometric test, the planes equally spaced from the zero plane are explored (that is, on both sides of the unit) and the average results given.

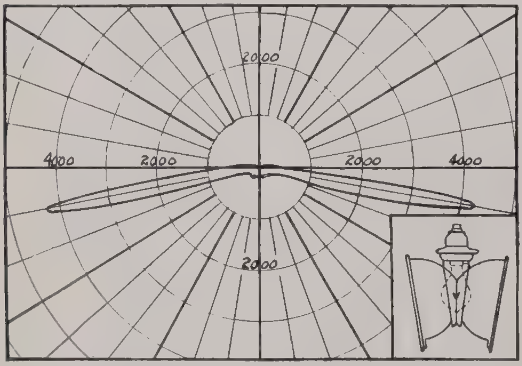


Fig. 1. Distribution of Candle-intensity in the Maximum Vertical Plane. These curves illustrate the difficulty of making a readable diagram of a narrow beam by the usual method of plotting

If the intensities at every 10 deg. of altitude and azimuth are known, it may be said that the unit has been fully explored with a photometer and the next step is to plot the data so that they can be understood. Needless to say, nine separate curves cannot be visualized and combined in mind so as to obtain a clear idea of the characteristics of the unit. The maximum intensity may be picked out and note made that it occurs at 81 deg. elevation and 90 deg. azimuth, but this will be the sole information ordinarily gained. The next necessary step is therefore the combination of the nine curves into a form that will again have the element of unity, and which will be simple enough so that anyone interested in the subject can readily understand and use the data.

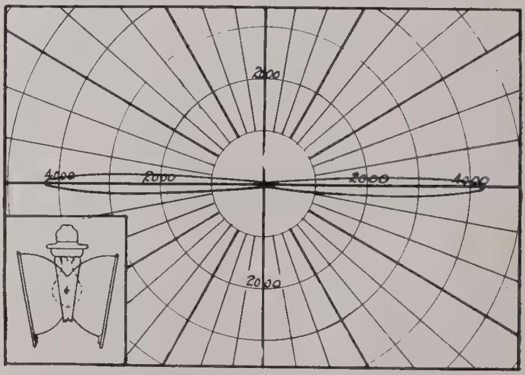


Fig. 2. Distribution of Candle-intensity in the 80-deg. Cone. An attempt to read these curves at the point of 10 per cent of maximum intensity reveals a fundamental weakness of this type of web

Spherical Projection Web

The ideal way of plotting the photometric distribution of an asymmetric unit would be on the surface of a large sphere centered about the unit. This sphere could be ruled off in degrees of longitude and latitude like a globe of the world, and it would then be an easy matter to plot on the sphere the light received by each section. We might explore the sphere and find all the points illuminated to an intensity of say 1000 candles, and if these points were connected by a smooth curve it would show at a glance the distribution of this particular intensity.

The difficulty with this method of spherical plotting is its unsuitability for general use, such as the photometric curves receive. Therefore it is necessary to employ a plotting surface that is flat so that a sheet of paper can be used.

There are several difficulties attending the transformation of a spherical surface into a plane surface but if certain sacrifices are made it can be done. In making maps of the world the cartographer has difficult work for if he tries to represent all countries in their proper shapes they will be to different scales, and if he plots all areas to the same scale the boundaries will be distorted. There are a number of map systems in common use, each of which gives a slightly different balance between size and shape, but practically all are incorrect in both these features. Fortunately for the illuminating engineer and his requirement, he does not care particularly about distortion but (as will be discussed later) the matter of area is of vital importance. The webs shown in Figs. 6 to 10 represent hemispheres in which there is considerable distortion of shape around the edges, but any section, such as that included between adjacent lines of latitude and longitude, is shown in its correct area.

ISOCANDLE DIAGRAMS

EXPLANATION OF WEB AND METHOD OF PLOTTING

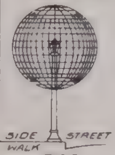


FIG. 3

"ISOCANDLE" MEANS A LINE OF EQUAL INTENSITY (IN CANDLES) PLOTTED ON ANY APPROPRIATE WEB. OR FORM

ISOCANDLE CURVES ARE USED ONLY FOR LIGHTING UNITS THAT GIVE AN ASYMMETRIC DISTRIBUTION OF LIGHT.

SUCH UNITS USUALLY DISTRIBUTE THE LIGHT IN THE SAME MANNER ON OPPOSITE SIDES OF A VERTICAL PLANE ACROSS THE ROAD OR STREET

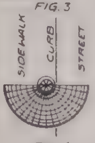


FIG. 4

THE INTENSITIES ON ONE SIDE ONLY OF THIS PLANE NEED BE PLOTTED ALTHOUGH THE TEST IS MADE ON BOTH SIDES AND AVERAGED

IMAGINE A HEMISPHERICAL SHELL PLACED ABOUT THE LAMP AS A CENTER AND HAVING ITS OPEN SIDE AGAINST THE ABOVE PLANE OF SYMMETRY. FIG. 3 IS A SIDE VIEW OF SUCH A HEMISPHERE, LOOKING ALONG THE STREET OR ROAD. FIG. 4 IS A TOP VIEW OF UNIT AND HEMISPHERE

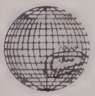


FIG 5

ON THIS HEMISPHERE A CURVE IS DRAWN FOR THE POINTS ILLUMINATED BY 1000 CANDLES; ANOTHER FOR POINTS ILLUMINATED BY 1500 CANDLES ETC. AND THESE CURVES ARE ISOCANDLE LINES AS SHOWN IN FIG. 5.

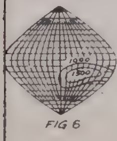


FIG 6

THE HEMISPHERE IS THEN FLATTENED OUT TO MAKE IT SIMPLE TO REPRODUCE ON FLAT PAPER, GIVING THE FORM SHOWN IN FIG 6.

Figs. 3 to 6 inclusive with their accompanying descriptions contain the complete instructions issued with the introduction of "isocandles" and the spherical web

The descriptive matter beside Figs. 3 to 9 gives a brief outline of the method of placing the hemisphere about the unit, but it will be realized that there can be no hard and fast rules relating the web and the light source. The asymmetric unit used in street lighting is designed to direct a beam of light up the street and another down the street. Each beam is directed outward from the curb so as to be centered on the street surface a hundred or more feet away. The unit may therefore be said to be right and left handed, and to have a plane of symmetry at right angles to the curb line. This plane cuts the enclosing sphere into two hemispheres, one of which is to be used as a plotting surface.

Isocandles

The word "isocandle" has been coined to indicate the type of curve here described. "Iso" has its usual meaning of "equal to" or "the same as," candle has its customary meaning with respect to light radiation, and the combination of the two is here taken as a curve joining points of equal candle intensity.⁽¹⁾ In Fig. 7 just above the equator a curve marked "300" crosses the web from edge to edge. The photometric exploration of this unit showed in each of the 18 vertical planes a point of 300 candles intensity within a few degrees of the horizontal, or equator of the web. These points were marked on the spherical web and when connected by a smooth curve gave the line shown. A few degrees lower there is a zone of 400 candles intensity. These curves are closed, for they each extend around the entire sphere, the opposite side of which is of course similar to the one shown except for being reversed right and left.

A zone of 500 candles passes to the left just below the horizontal around to 145 deg. (longitude) and then turns down and back to the right, so that in the hemisphere shown there is in this reversal of the curves evidence of a peak of intensity that does not extend completely around the unit. The isocandle for 1200 candles is a closed curve which marks the location of a peak of intensity about 14 deg. below the horizontal and 25 deg. from a line directly across the street. The 1100 isocandle closes within a degree of the edge of the hemisphere, but the 1000 isocandle extends to the edge and has its turning point within four degrees of the plane of the curb. This unit might therefore be roughly described as giving a

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(1) A somewhat similar combination occurs in the word "isobar" used by the U. S. Weather Bureau on weather forecast maps to indicate points of equal barometric pressure.

fan-shaped beam 172 deg. wide at about 15 deg. below the horizontal, with two peaks of intensity of over 1200 candles separated by 50 deg. This description is of course incomplete and not sufficiently definite to be of great service, but it contains about all the information ordinarily given by photometric curves of this type of unit.

Without paying any attention to the marking on the curves other than to note that the 1200 isocandle is a peak and not a valley, an inspection of the diagram shows:

(a) A fan-shaped beam about 180 deg. wide extending over the street.
(b) This fan of light is about 15 deg. below the horizontal, or at an elevation of 75 deg.
(c) There are two peaks of intensity.
(d) The decrease of light is much more rapid above the fan than below it.
(e) Around the horizon the intensity is not far from uniform.
(f) At an elevation of 30 deg. the intensity is not far from uniform.
(g) There is a general decrease of intensity from the plane of the curb around toward the houses.
(h) There are several minor peaks of intensity in the upper hemisphere, but on account of their low intensity they are of small importance.

Items (a) to (h) will be at once apparent to anyone familiar with topographic maps, but a closer inspection will of course be required to determine the actual values involved and the precise intensity of the "peaks" outlined by the small closed curves. The actual maximum will seldom be an even number and therefore the maximum intensity, 1252 candles, is printed at some convenient place on the web.

The isocandles are for differences of 100 candles except that the 150-candle curve has been inserted to fill in the large area between the two sets of 200 isocandles in the upper hemisphere. A broken line has been used to indicate that this isocandle does not follow the regular spacing of 100 candles.

A lantern type unit gives an isocandle plot that is highly characteristic. The ribs cast shadows and the various structural and

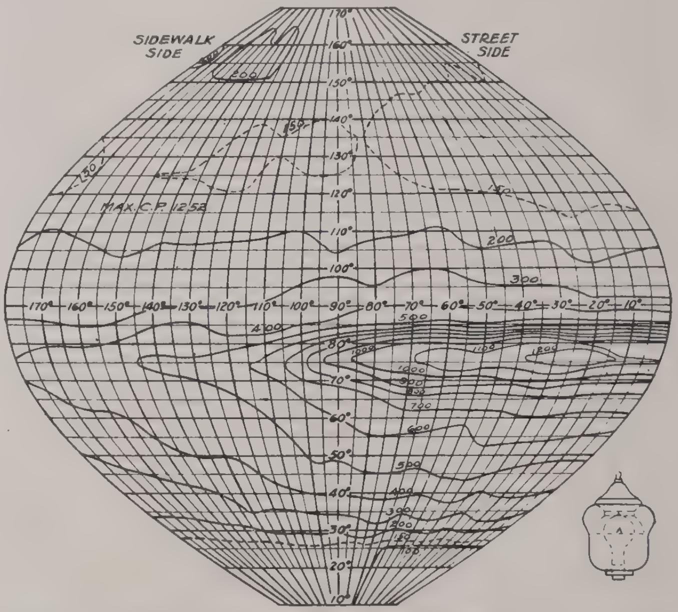


Fig. 7. Isocandle Diagram for a Unit that is designed to give added efficiency of projection to the surface of the street and at the same time avoid too great a concentration of light in any one direction

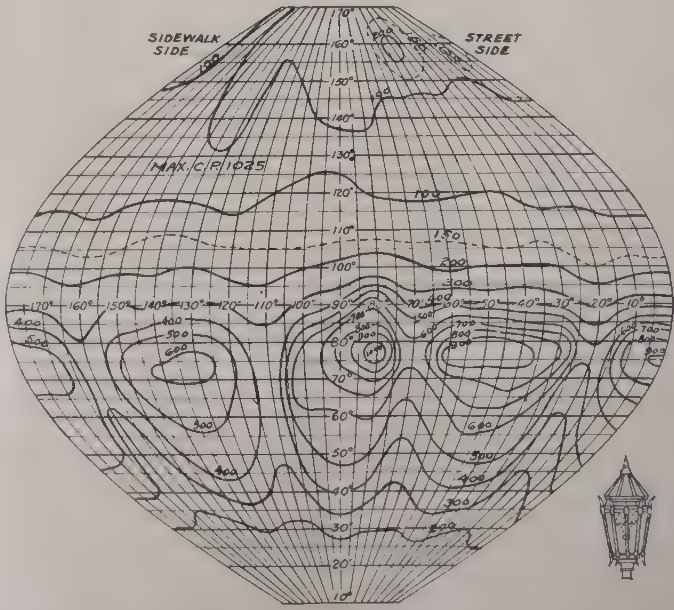


Fig. 8. The effect of the ribs on the distribution of light is very obvious from the general appearance of this diagram

ornamental parts have effects on the distribution of light that are readily recognizable in the isocandle diagram. The isocandle plot of light distribution from one such unit is shown in Fig. 8. This line diagram is the standard and final form recommended for the visual representation of such data. From it, the imagination can readily conjure a picture of the light distribution by visualizing the zones between isocandles as graded in light and shade to represent the variations in intensity. An actual rendering of this sort appears as the cover illustration of this issue, though in it every alternate isocandle in Fig. 8 is omitted for the sake of simplicity, and the shading progresses by definite steps rather than by the continuous variations that actually exist. As will be noticed in both the cover illustration and Fig. 8, there are three complete peaks of intensity and two half-peaks included in the hemisphere, indicating a total of eight peaks corresponding to the eight panels. The valleys between peaks correspond to the shadows of the ribs and these valleys are traceable nearly from pole to pole of the sphere. There are two 100-candle zones in the upper hemisphere and the intensity between these zones is a region of intensities less than 100 candles but greater than 50 candles. This is evident from the presence of an inserted 150 isocandle, indicating that if any intensities of 50 candles had been found they would have been plotted.

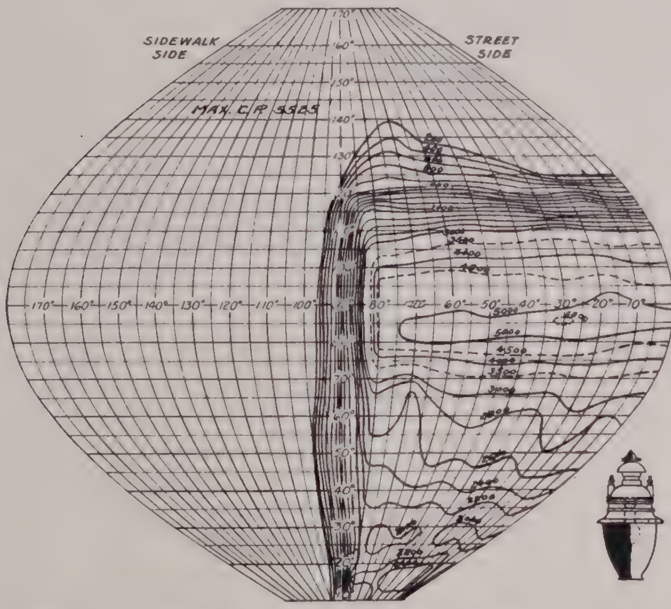


Fig. 9. The unit in this diagram concentrates all its light on one side of the plane of the curb, and most of this light is below the horizontal

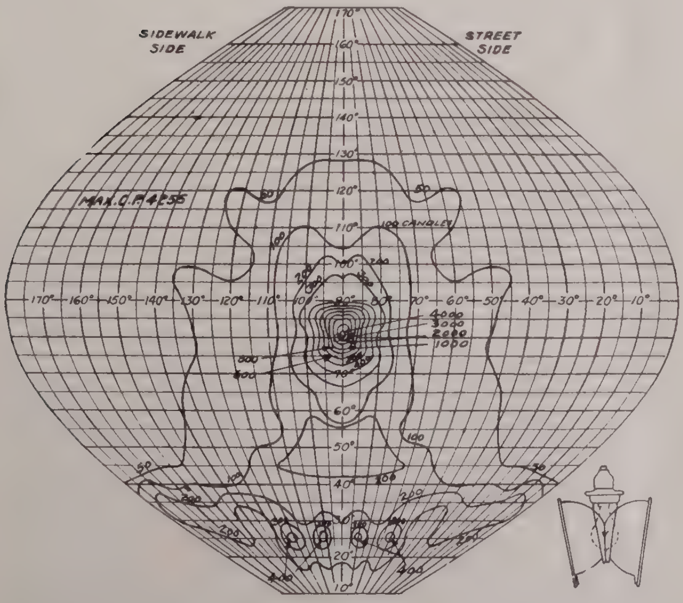


Fig. 10. Diagram Representing the Complete Exploration of the Same Unit from which the Curves in Figs. 1 and 2 Were Derived

A special case of light distribution is illustrated in Fig. 9. The globe of this unit is silvered around an arc of 180 deg. and there is therefore a wide region of total shadow. The plot shows the light to be confined within about one-third of the visible hemisphere, with a rapid rise of intensity from a definite and sharp cut-off or beam boundary. The isocandles are spaced 200 candles apart up to 3000 candles. At this point the lines become more crowded and a spacing of 500 candles is used. The choice of spacing is obviously a matter of taste, and in this particular case a uniform spacing of 500 candles might have been better.

As noted before, a closed curve may indicate either a region of high intensity or one of low intensity. At the bottom of Fig. 8

both kinds occur within a few degrees of one another. The 2000 isocandle lies between two 2200 isocandles, showing that it marks a region of low intensity or valley. The 2400 isocandle is partially enclosed by the 2200 isocandle and it therefore indicates a peak or region of high intensity.

The unit giving the distribution of light shown in Figs. 1 and 2 was later retested in several additional planes and the results plotted in Fig. 10. On account of the wide range of intensities it was not thought best to attempt a uniform spacing of the isocandles, which are plotted for 50, 100, 200, 300, 400, 500, 600, 800, 1000, 2000, 3000, and 4000 candles. This particular unit is used under conditions that make the regions of 100 and 200 candles intensity of considerable engineering importance, and this type of plotting allows the presentation of many facts that could not ordinarily be shown by the usual methods.

"Maximum Vertical Plane"

In the case of a unit giving an asymmetric distribution, it has been customary to plot two special distribution curves. One of these has been called the "maximum vertical plane" because it has been selected to contain the point of maximum intensity. The plane as a whole may not show a maximum average intensity and therefore the title is sometimes a little misleading. The unit in Fig. 8 might properly call for five different curves each in a vertical plane passing through a peak, of which there is one of 500+ candles, two of 600+ candles, three of 900+ candles, and two having the real maximum of 1025 candles. There are thus eight peaks, six of which occur in pairs and only five curves are required. The plotting of these curves from the isocandle diagram is readily done by first selecting the vertical plane that passes through the selected maximum (in this case the 80-deg. line of longitude) and noting the angular elevation of the crossing points of the various isocandles.

"Maximum Conical Distribution"

The second special distribution curve made for an asymmetric unit is in the cone containing the maximum intensity. In the case of Fig. 8, a cone at an elevation of 75 deg. passes through all eight regions of maximum intensity, and one conical distribution suffices.

Web Areas and Lumen Values

One of the great disadvantages of the usual distribution curve is the almost total lack of scale relating the size of the curve to its light flux value. If on a given web such as in Fig. 1, the intensities are reduced one-half the area shrinks to one-quarter; and in the particular case shown, the curve would become almost unreadable. Also, equal quantities of light directed along the axis of a lamp and distributed around the equator give curve areas that are enormously different. For example, 10 lumens in the zone from the axis to 10 deg. gives an intensity of 105 candles, while the same 10 lumens uniformly distributed in a 10-deg. zone around the equator give an intensity of 9.2 candles, a variation of eleven to one, and a range that is practically impossible to plot with any accuracy in the ordinary way. On account of the small importance of the 0-10 deg. zones, they have been omitted from the web in order to make room for other data. By the isocandle method the accuracy of plotting and reading is the same in all zones providing that the isocandles are plotted by proportional steps for both high and low intensity. In the particular case of Fig. 10, this condition was approximated and the reading accuracy is perhaps as good at all points as the nature of the unit permits.

A direct result of the lack of scale in the area of the usual distribution curve is the great exaggeration of illuminating value given to the light near the axis as compared with light near the equator. This has frequently led to erroneous comparisons between units, and among engineers familiar with this particular distortion it has led to a very positive demand for "downward lumens," "total lumens," and other data that eliminates any need for using the area of the distribution curve as a measure of output. The isocandle diagram is in exact scale at all parts, and where a given intensity near the equator has more flux value than when near the poles the fact is plainly indicated by an exactly proportional relation between the areas on the diagram.

Charles A. Coffin Foundation Awards to General Electric Employees for 1924

We publish with pleasure the second annual list of General Electric employees to receive awards from the Charles A. Coffin Foundation. They are a representative group of men, located in many departments and in widely separated plants, and their unusual initiative has been applied to diverse fields within the Company's scope. These men offer many examples of deep technical insight and moral courage.

In any industry there are bound to be many workers whose cast of mind and pioneering spirit is such as to lead them to make important contributions to the arts from the practice of which they derive their livelihood. It is no more than fitting that such men should receive public acclamation and monetary reward for their special achievements.

The list of awards which follows brings to light one of the most fundamental laws upon which the progress of human nature is based—the general law of change and desire for improvement. When a man becomes satisfied with things as they are, he, curiously enough, does not stand still, but actually drops backward. When, on the other hand, he comes to regard his environment as only relatively satisfactory, his innate inventive genius is stirred and progress results. While in general the majority tend to move with the current and consequently to become a source of inertia to progress, the forward pressure imparted by the few who exhibit independence of thought and action is sufficient to keep civilization in steady motion upstream. In our own case the electrical industry has received important contributions from the men named in this list. The state of the art is distinctly further along today as the result of the voluntary and unsolicited contributions of which we are about to make note.

In looking through the list it is interesting to see the great variety of the citations. Fields of work are represented which at first thought would not appear to be within the realm of the electrical industry at all. The explanation lies in the fact that the manufacture of electrical apparatus must be based not only on the principles of electricity but also upon a sound knowledge of physics, chemistry and mechanics. Research and development along the lines of practically every science are necessary to insure the fundamental worth of the electrical product. Thus we find awards made for the discovery of methods of manufacturing fused quartz, for improvements in automobile timing gears made from cotton cloth, and for important theoretical work on the metallurgy of steels. We find a man who learned to solder aluminum to copper, and another who has greatly reduced the time required in covering castings with a coat of paint. In short, the field is limitless and we cannot be surprised at any of the ramifications that we may find.

The complete list of the Charles A. Coffin Foundation awards follows:

SHOP WORKMEN

ROBERT BRINDLE, Experimental Machinist, Edison Lamp Works. Invented a bead feeding device in automatic machines, used in butt-seal miniature lamp making.

MARCO CEFALETTO, Scrap Department, Schenectady Works. Suggested a method of salvaging monel metal scrap.

JOHN FLAWS, Jr., Experimental Machinist, Edison Lamp Works. Developed a machine for producing filaments for UV-199 radiotrons.

WILLIAM MCNAUGHTON, Gang Boss, Punch Press Department, Schenectady Works. Improved the construction of enamel furnaces.

RICHARD S. NASSIF, Oven Tender, Pittsfield Works. Suggested the installation of a conveyor system; thus eliminating the necessity for his job.

BERTHOLD F. NIEDERGESASS, Quartz Worker, Thomson Laboratory, River Works, Lynn. Developed machine methods to replace hand methods in producing quartz tubing.

GEORGE W. REDMOND, Enamel Wire Machine Operator, River Works, Lynn. Suggested an improved form of gas burner for enamel wire oven.

THEODORE ALFRED RICH, Testing Department, West Lynn Works. Invented a method of soldering aluminum.

PAUL F. WAGNER, Mechanic, National Lamp Works. Developed a butt-sealing machine which greatly increases production and reduces the cost of sealing lamps.

SAMUEL T. WILLIS, Taping Machine Operator, Schenectady Works. Produced and installed and successfully operated an adjustable paper guide for high-speed taping machines.

Frank B. Van Sickle, Mechanic, National Lamp Works. Invented and developed an automatic device for use on Westlake bulb-blowing equipment.

Edward D. Zink, Transformer Inspector, Pittsfield Works. Suggested improved method of anchoring low-voltage leads in distribution transformers.

FOREMEN

Herman O. Grotjohann, Screw Machine Department, River Works, Lynn. Improved the mechanical operations and the general usefulness of his department.

Edwin D. Houghton, Field Coil Department, Schenectady Works. Exceptional ability shown in performing his duties as foreman and in suggesting improvements in the design of field coils.

George Illingworth, Development Laboratory, National Lamp Works. Developed an automatic machine of extraordinary efficiency for the production of butt-seal mounts for incandescent lamps.

Sydney F. Nethaway, Testing Department, Schenectady Works. Displayed unusual skill and originality in improving painting operations.

Charles Panthen, Shipping Department, Schenectady Works. Developed in an emergency an efficient waterproof packing material.

ENGINEERS

Charles Burgeson, Minneapolis Office, who has been with the Company thirty-six and one-half years. Invented and designed a combination fuse and disconnecting switch. If any one of the fuses is blown all three blades of the disconnecting switch immediately open and the switch cannot be closed until the fuse is replaced.

Wendell L. Carlson, Radio Engineering Department, Schenectady, who has been with the Company two years. Mr. Carlson, with Glenn W. Carpenter, was responsible for important developments of the super-heterodyne, and for apparatus used for development and testing of catacombs. He designed and built apparatus based on the tube voltmeter principle to be used in developing the circuit. It is largely through his resourcefulness, initiative and untiring efforts that our Company has been so successful in its Radiola Super-heterodyne and Radiola VIII program.

Glenn W. Carpenter, Radio Engineering Department, Schenectady, who has been with the Company two years. Mr. Carpenter was responsible for the catacomb construction used in Radiola Super VIII and Radiola Super-heterodyne receivers. He also originated a semi-automatic curve drawing instrument used in testing these catacombs. The "cat" concentrates the vital parts of an otherwise complicated construction into a small space where the transformer coils and other devices may be connected by means of their own small wires.

Philip K. Devers, Electro-chemist, Thomson Laboratory, River Works, Lynn, who has been with the Company thirteen years. Mr. Devers has specialized on tungsten arc and clear fused quartz development, and was eminently successful in solving the problem of fused quartz production in large clear masses, called ingots. He was also responsible for the experimental development up to practical success of a form of tungsten arc lamp.

Edward H. Freiburghouse, Designing Engineer, Turbine Generator Section, A-C. Engineering Department, who has been with the Company fifteen years. Mr. Freiburghouse improved the ventilation of turbine-driven generators by grooving their rotors, thus reducing eddy losses and increasing the rotor surface for cooling purposes.

Emil J. Guay, Designing Engineer, Fabroil and Textolite gears, River Works,, Lynn, who has been with the Company twenty-six years. Mr. Guay improved designs and processes used with textolite gears which have formed the basis of important patents. He developed moulded gear blanks as distinguished from gear blanks machined out of boards or squares, and developed a method of vacuum treatment for removing surplus bakelite.

Isaac F. Kinnard, West Lynn Works, who has been with the Company two years. Mr. Kinnard developed a series of copper-nickel-iron alloys that have a very large temperature coefficient of permeability, which have aroused the enthusiastic attention of engineers. He has been able to develop a measuring equipment, by using these alloys, with which accurate results in measuring the characteristics of current transformers may be obtained down to one per cent of load, with a lower burden on the transformer than has heretofore been necessary.

Thomas H. MacCauley, Switchboard Department, Schenectady, who has been with the Company eight years. Mr. MacCauley devised a system of standardization of switchboard designs to maintain greater uniformity regardless of where and by whom designed, and to reduce to a minimum the variety of copper details. He set out to do a stupendous task, determined to have it workable to the last detail before presenting it for consideration, and submitted drawings complete except for the G-E number.

Jacob W. McNairy, Railway Equipment Engineering Department, Schenectady Works, who has been with the Company eight years. Mr. McNairy invented, and in connection with Louis W. Thompson, developed, an electrically-operated flowmeter for measuring steam, water or air. This instrument has since proved highly successful and a large order specifying it has been placed with the Company.

Ronald S. McNeil, Edison Lamp Works, who has been with the Company for six years. With Albert L. Smith, Mr. McNeil developed a method of automatic gas control for changes in gas quality. It consists of an automatic regulating device which definitely controls not only the flame temperature, but also the position of the point of maximum heat. It compensates for changes in gas quality due to changes in specific gravity, constituents of gas, or B. T. U. value.

Levi B. Miller, Electro-chemist, Thomson Laboratory, River Works, Lynn, who has been with the Company seventeen years. Mr. Miller worked out a process and apparatus for forming ingots of fused quartz into products such as long rods and tubes, demanded by the art, as in the construction of the ultra-violet lamp with the mercury arc.

Albert L. Smith, Edison Lamp Works, who has been with the Company for seventeen years. Mr. Smith, with Ronald S. McNeil, developed a method of automatic gas control for changes in gas quality. It consists of an automatic regulating device which definitely controls not only the flame temperature, but also the position of the point of maximum heat. It compensates for changes in gas quality due to changes in specific gravity, constituents of gas, or B. T. U. value.

Louis W. Thompson, Flow Meter and Regulator Engineering Department, Schenectady Works, who has been with the Company ten years. With Jacob W. McNairy, Mr. Thompson invented and developed an electrically-operated flow meter for measuring steam, water or air. The mechanical flow meter, formerly built, did not altogether harmonize with the general line of products manufactured and sold by General Electric.

Harry W. Tobey, Pittsfield Works Laboratory, who has been with the Company twenty-seven years. He designed and developed machines for use in straight line and circular resistance welding for sheet steel tanks. They produced tighter, more reliable seams of greatly improved appearance, and welding can be done at substantially increased speeds and with greater comfort to operators, at a large cost reduction.

Max A. Whiting, Industrial Engineering Department, who has been with the Company nineteen years. He invented and developed a system of direct-current motor control known as the exciter system, which has revolutionized the operation of high-speed elevators. It provides greater security to the elevator when running at full speed and when approaching the limits of travel, and provides greater ease and promptness of landing at floors with required accuracy.

COMMERCIAL

C. A. Atherton, National Lamp Works, who has been with the Company five years. Mr. Atherton developed the theory and practice making possible the scientific design of electric signs of exposed lamp type, so as to assure attractiveness and legibility at specified distances.

Henry G. Issertell, Building Equipment Section, New York Office, who has been with the Company twenty-four years. He developed and placed in successful operation a plan for providing architects and consulting engineers with working data on G-E products. Data were assembled in a special Data Book in ready reference form, and made such information as photographs and dimensions of apparatus easily available.

Harry C. Meyers, Name Plate Engineer, Publicity Department, Schenectady Works, who has been with the Company twenty-four years. Mr. Meyers produced an acid-proof and weather-proof name plate after laboratories had tried to do so for three years. Mr. Meyers developed a process of direct printing by lithography on an enamelled steel name plate, which is permanent under all conditions.

Hylan T. Plumb, Engineer, Salt Lake City Office, who has been with the Company fourteen years. When the Castle Gate Mine disaster took place in Utah, Mr. Plumb went to the scene of the disaster and helped in the rescue work for six days. He initiated a systematic direction of the work at the mine portal through which bodies were brought from the mine, and organized a telephone service for rescuers in the mine.

Perlee A. Sexsmith, Salesman, Industrial Department, Chicago Office, who has been with the Company fifteen years. Mr. Sexsmith, while visiting a customer in connection with a proposition covering large centrifugal blowers, discovered a new application for flow meters. He called in a flow meter specialist and assisted in securing one of the largest orders ever received by the Company for flow meters. The new application was the measurement of air and sewage in a sewage disposal plant.

L. Wakefield Shugg, Assistant to Manager of Conventions and Exhibits, Schenectady, who has been with the Company twenty-three years. He has reflected great credit upon the General Electric Company and materially increased its prestige by his tact, courage, and resourcefulness in his relations with other manufacturers, many of whom are active competitors of this Company. He served as director of all exhibits at the May, 1924, convention of the N.E.L.A., at the request of the Association, and with remarkable success.

Walter C. Smith, Transformer and Meter Specialist, San Francisco Office, who has been with the Company nineteen years. Mr. Smith arranged an unusual sales exhibition, which involved more than usual foresight and executive ability. He also made a clever design for increasing the secondary voltage on transformers rated 22000/400-122/244, although it was out of his regular line of duty.

SPECIAL AWARDS

Clarence C. Bailey, Engineer, Railway Department, Schenectady Works, for presentation of the subject "Steam Railway Business," in a paper read at Camp Commercial, July 2, 1924.

George H. Calkins, Manager, Buffalo Office, for his presentation of the subject, "Co-ordination of Effort," in a paper read at Camp Commercial, July, 1924.

Charles P. Bloomer, Superintendent, Philadelphia Works, for his presentation of the subject, "Fitting a Man to His Job," in a paper read at Camp Manufacturing, July 2, 1924.

John St. Lawrence, General Superintendent, Erie Works, for his presentation of the subject, "Relation of Limits and Allowances to Cost Production," in a paper read at Camp Manufacturing, June 25, 1924.

LIBRARY SECTION

Condensed references to some of the more important articles in the technical press, as selected by the G-E Main Library, will be listed in this section each month. New books of interest to the industry will also be listed. In special cases, where copy of an article is wanted which cannot be obtained through regular channels or local libraries, we will suggest other sources on application.

Arc Welding

Arc Welding in Power Plants. Warner, W. L.
Power, Mar. 3, 1925; v. 61, pp. 336-338.

Electric Arc Welding in the Steel Industry. Warner, W. L.
Am. Weld. Soc. Jour., Feb., 1925; v. 4, pp. 9-17.

Corrosion

Causes and Controlling Factors in the Corrosion of Iron and Steel. Wood, W. P.
Am. Soc. St. Treat. Trans., Mar., 1925; v. 7, pp. 321-336.

Electric Distribution

Distribution System Engineering. Caster, J. H.
Elec. News, Mar. 1, 1925; v. 34, pp. 59-61.
(Author is Assistant Engineer, Hydroelectric Power Commission of Ontario.)

Generating Sets

Submarine Engines and Heavy-Oil Engine Electric Generating Sets. Holliday, P. A.
Engng., Feb. 27, 1925; v. 119, p. 276.
(Abstract of a paper read before the Diesel Engine Users Association, England.)

High Frequency

Effect of Oxidation on the High-Frequency Resistance of Aerial Wires: with a Note on Measuring the Resistance of Thick Wires. Turner, L. B.
I.E.E. Jour., Jan., 1925; v. 63, pp. 149-153.
(Presents results of tests.)

Lubrication and Lubricants

Lubrication of Electric Street Railways.
Lubrication, Jan., 1925; v. 11, pp. 1-12.
(Includes information on railway motor lubrication.)

Protective Apparatus

Survey of Automatic Alternating-Current Protective Apparatus. Nuttall, B.
I.E.E. Jour., Jan., 1925; v. 63, pp. 147-148.
(Abstract of a paper read before the North-Western Students' Section of the Institution of Electrical Engineers.)

Railroads—Electrification

St. Paul's Electrification Shows Economies Over Steam.
Rwy. Age, Feb. 28, 1925; v. 78, pp. 514-518.
(Presents detailed statistics showing a comparison of operating costs with electric and with steam operation.)

Standards, Electric

Insulator Test Specifications.
A.I.E.E. Jour., Mar., 1925; v. 44, pp. 300-303.
(Proposed standard specifications of the American Institute of Electrical Engineers.)

Transient Phenomena

Power System Transients. Bush, V. and Booth, R. D.
A.I.E.E. Jour., Mar., 1925; v. 44, pp. 229-240.
(Presents methods of analysis of such transients. Abridgment of complete paper.)

Wattmeters

Temperature Errors in Induction Watthour Meters. Kinnard, I. F. and Faus, H. T.
A.I.E.E. Jour., Mar., 1925; v. 44, pp. 241-248.
("An analysis and the development of a temperature-sensitive magnetic material suitable for compensation." Abridgment of complete paper.)

NEW BOOKS

Circuit Troubles and Testing. Terrell Croft. 224 pp., 1924, N. Y., McGraw-Hill Book Co., Inc.

Connecting Induction Motors. Ed. 2. A. M. Dudley. 361 pp., 1925, N. Y., McGraw-Hill Book Co., Inc.

Cost Accounting Theory and Practice. James L. Dohr. 631 pp., 1924, N. Y., Ronald Press Co.

Electric Cables; Their Design, Manufacture and Use. William A. Del Mar. 208 pp., 1924, N. Y., McGraw-Hill Book Co., Inc.

Elements of Statistics. Frederick C. Kent. 178 pp., 1924., N. Y., McGraw-Hill Book Co., Inc.

Graphic Analysis for Executives. Winfield A. Savage. 141 pp., 1924, N. Y., Codex Book Co.

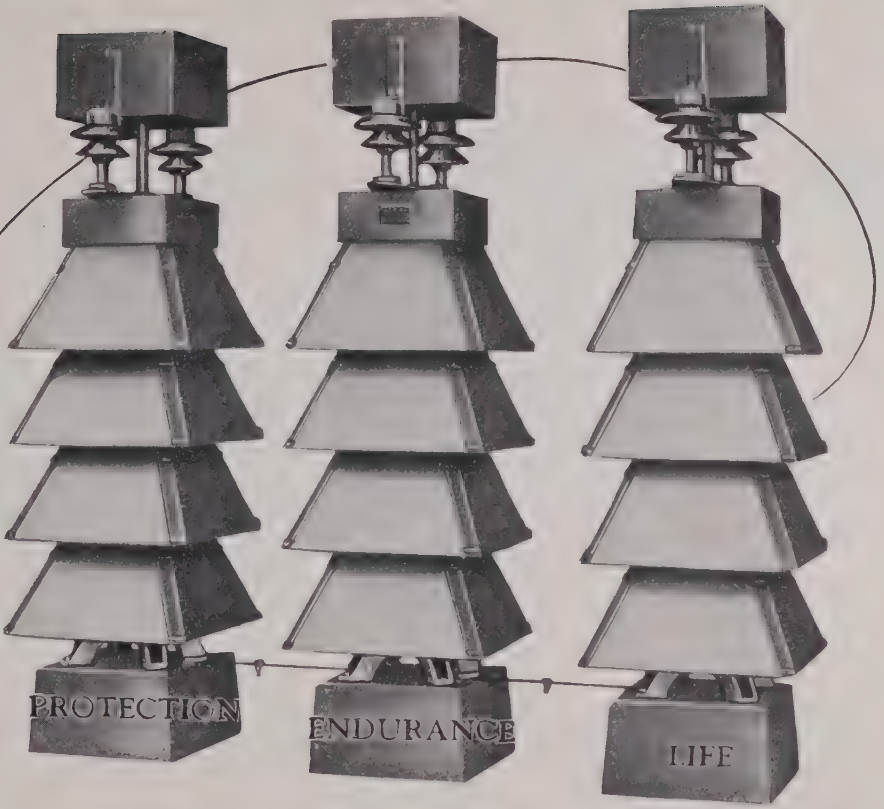
Mathematics for Technical Students. E. R. Verity. 468 pp., 1924, N. Y., Longmans, Green & Co.

Scientific Research and Human Welfare. Franklin S. Harris and N. I. Butt. 406 pp., 1924, N. Y., Macmillan Co.

Statics, Including Hydrostatics and the Elements of the Theory of Elasticity. Ed. 2. Horace Lamb. 357 pp., 1924, Cambridge, England, University Press.

Switchgear for Electric Power Control. E. Basil Wedmore and Henry Trencham. 335 pp., 1924, Lond, Humphrey Milford.

Technical Mechanics, Statics, Kinematics, Kinetics. Ed. 5. Edward R. Maurer and Raymond J. Roark. 364 pp., 1925, N. Y., John Wiley & Sons.



The Foundations of the Oxide Film Arrester

PROTECTION— An eight years' record—20,000 arrester-years of experience with the station type alone—tells the story of Oxide Film protection. Operating experience merely confirms results obtained from tests.

ENDURANCE— The Oxide Film Arrester has a cell nearly 23 sq. in. in area and ½ inch thick to take the discharge and dissipate the heat. The arrester with the highest heat-dissipating quality is least likely to be injured.

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20-8B

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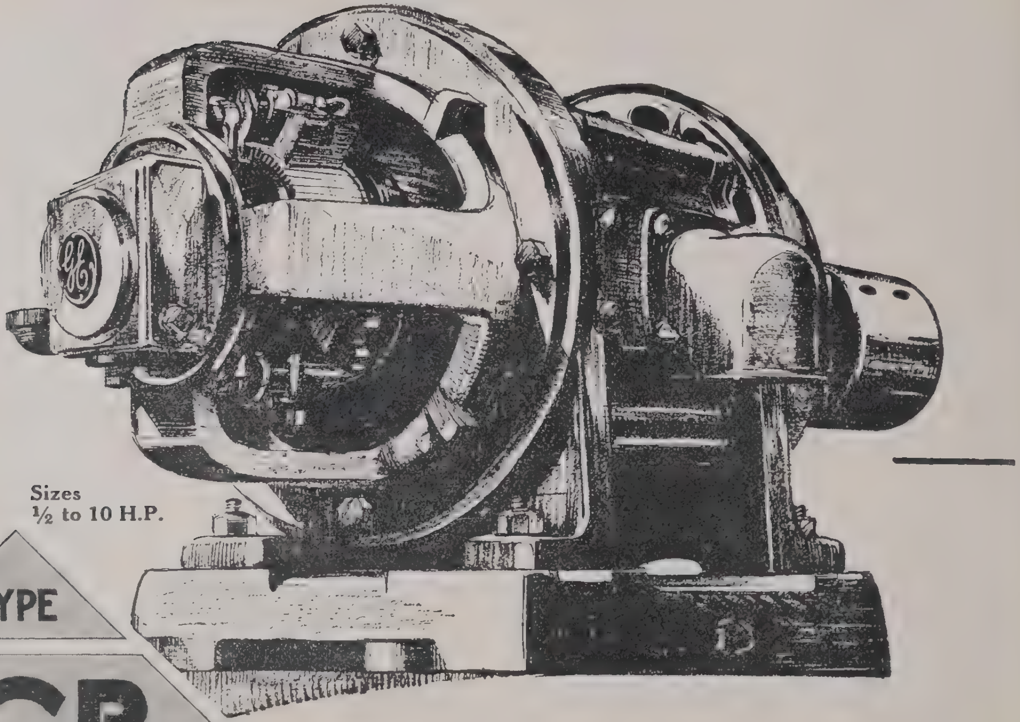

Sizes
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TYPE

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MOTOR

Characteristics:

High Torque
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—"Pull Out"
High Efficiency
High Power Factor
Low Starting Current
Low Heating
Excellent Commutation
—Overload Capacity
—Speed Regulation
Quiet
—Starting
—Running
Positive operation
on low voltage

the Single Phase Motor with *reserve power*

Most automobiles on smooth roads, once up to speed, pull the load. The "real car" negotiates the big hills or heavy roads "on high."

The type SCR motor has the same *reserve power,* first to start then to accelerate the load up to full speed and finally to sustain that speed at overloads.

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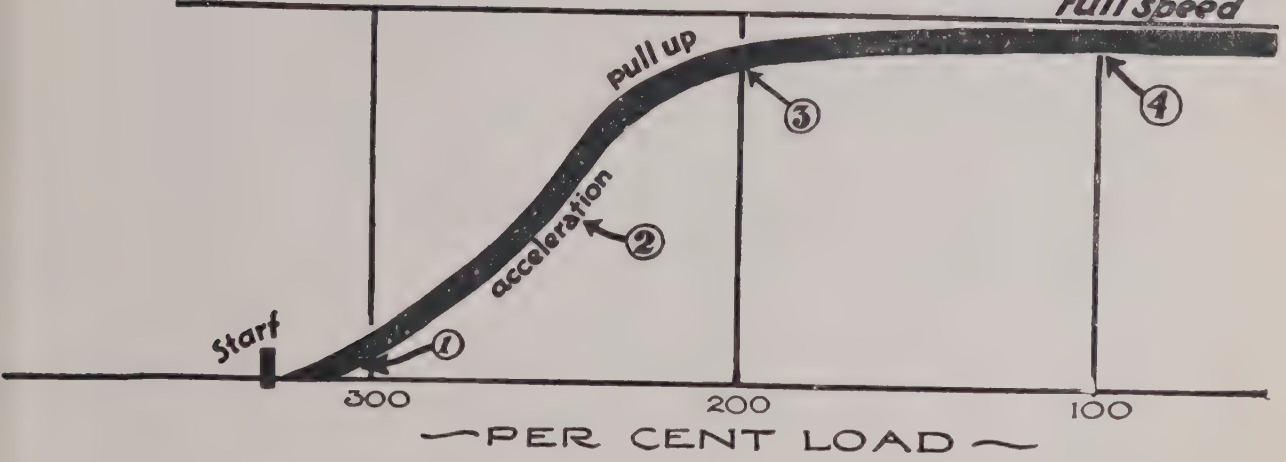

Smooth acceleration!

"Start"............ An **SCR** in starting exerts a powerful twist or torque-3 times that required at full *speed*!

"Acceleration"... The **SCR** motor does not "*hang*" at any point while accelerating

"Pull up"........... The **SCR** has a "pull up" torque twice that at full load

"Overload"..... The **SCR** motor will sustain a heavy momentary overload without unduly slowing down

7D-3

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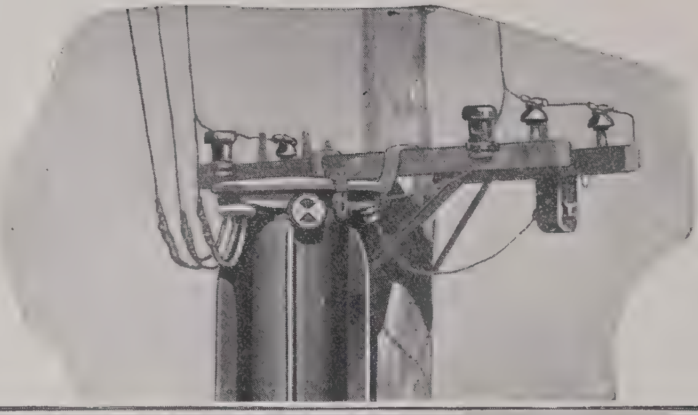
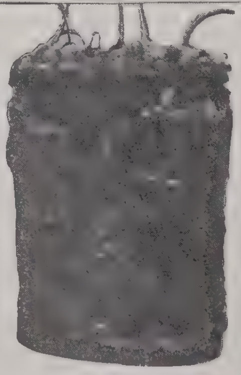


Type H The Standard of Transformer Quality



This Type H, removed because its load had outgrown its capacity, had given continuous service for 18 years. After "cleaning and painting" it was again ready for the line.

Satisfaction

measured in years

Millions of Type H transformers have been delivered to power and light companies.

G-E responsibility for satisfactory service becomes an acute matter under such circumstances.

Manufacturing standards and testing standards are necessarily strict and strictly enforced—not merely out of manufacturing pride but as an economic necessity.

Hence, the high "factor of safety" as regards the length of service embodied in Type H Transformers.

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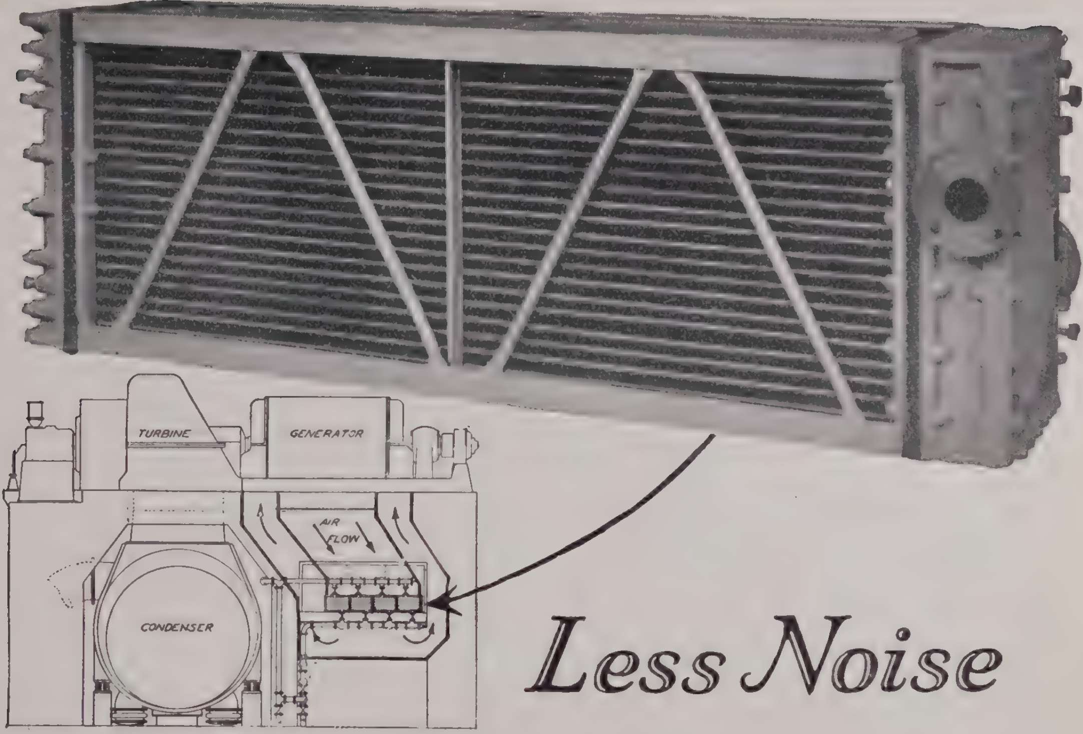

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Cool your generator air with G-E Surface Air Coolers

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Clean, dry generator air
Waste heat saved for feed water
Simple air ducts

You can easily install G-E Surface Air Coolers for existing equipment. By all means include them in new installations.

Bulletin 45609

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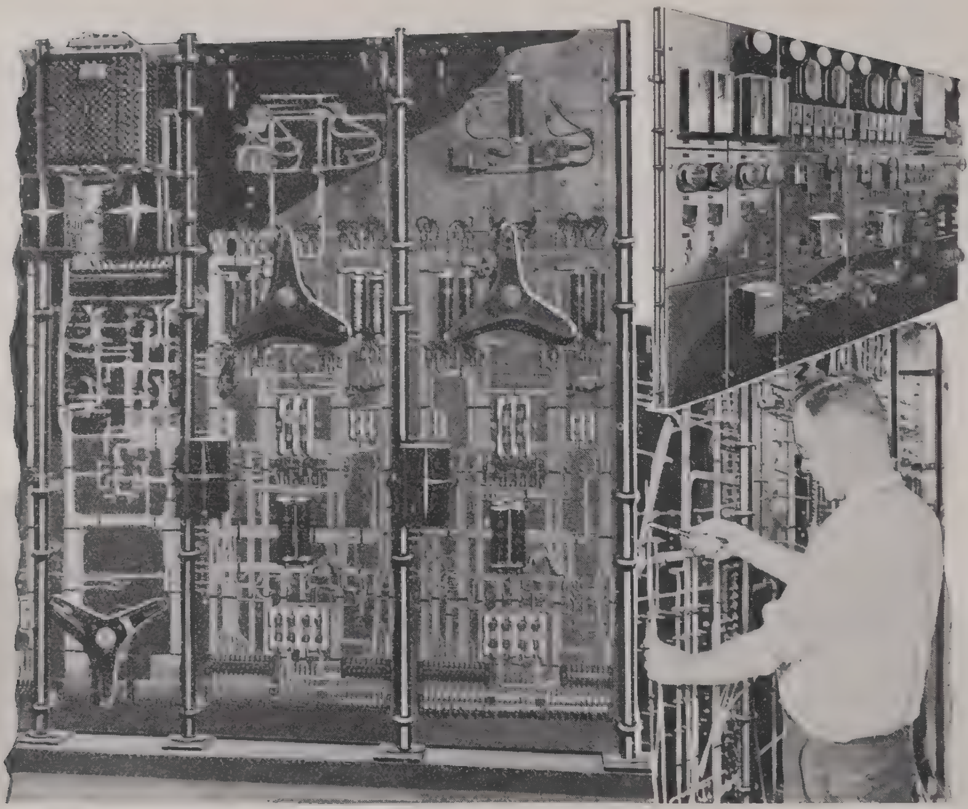

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Stand back of any switchboard and you will see why good control wiring is essential to reliability. One loose contact or a broken wire can cause an expensive failure.

Stand back of a G-E Switchboard and you will see that much importance is attached to this back-of-board workmanship. The control wire, wire cleats, terminals and terminal boards all meet the rigid standards that establish character in General Electric Switchboards.

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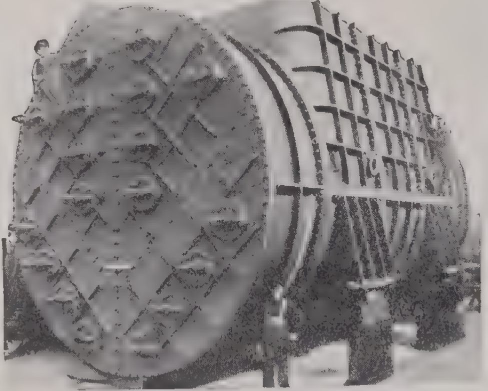

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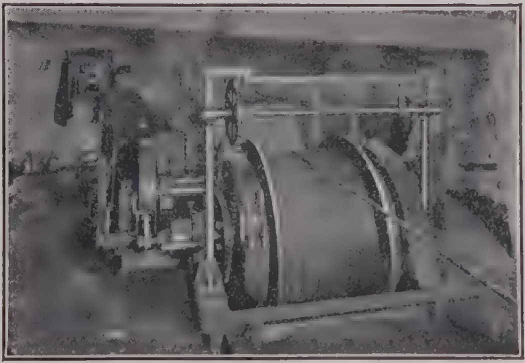

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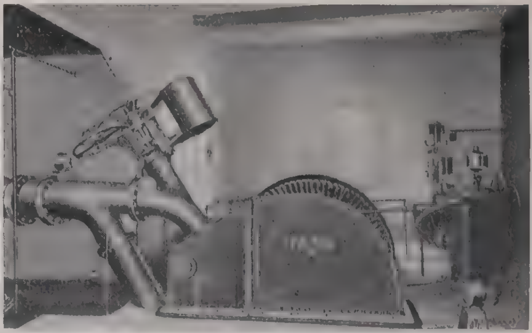

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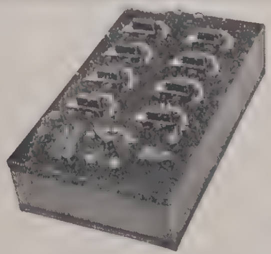

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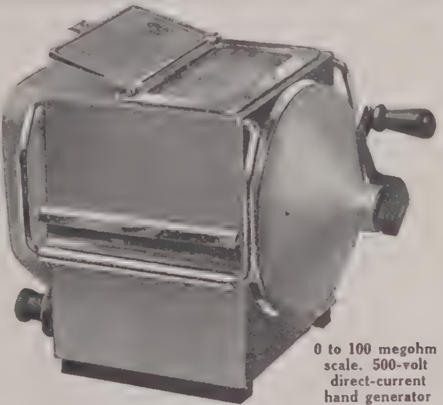

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Drum, A. L. & Co. 30
Electric Bond and Share Co. 16
Elliott Company 3
Foundation Company, The 30
General Electric Company 17, 18, 19, 20, 21, 22
General Radio Co. 27
Griscom-Russell Co., The 15
Gurney Ball Bearing Co. 24
Indiana Steel and Wire Co. 26
Ingersoll-Rand Co. 8
Irvington Varnish and Insulator Co. 28
Keystone Lubricating Co. 13
Lidgerwood Mfg. Co. 25
Link Belt Company .... Back Cover
Locke Insulator Corp. 6
Maqua Company 23
Marlin-Rockwell Corp. 24
McClellan & Junkersfeld 30
Milliken Brothers Mfg. Co., Inc. 11
Morse Chain Co. 12
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Starrett Co., The L. S. 25
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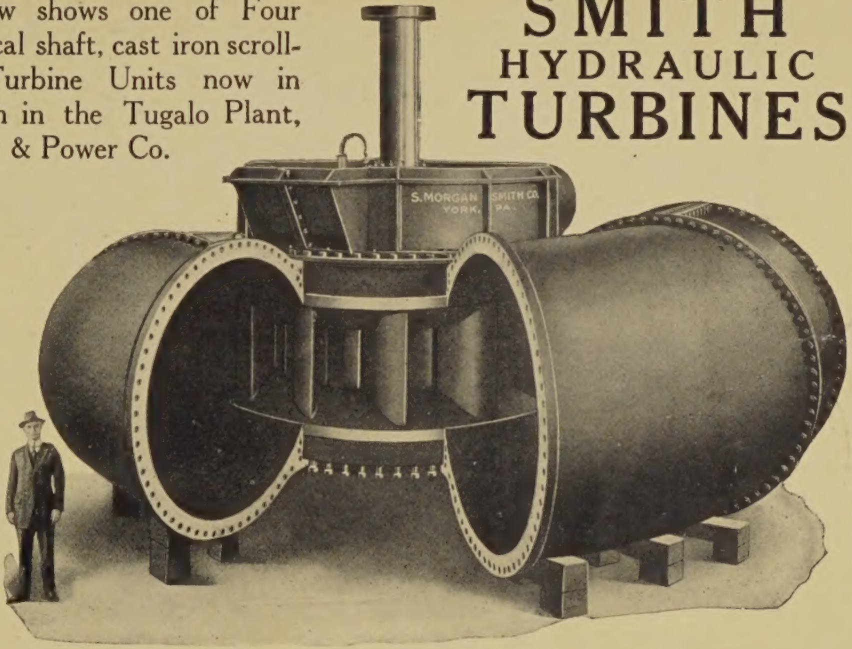

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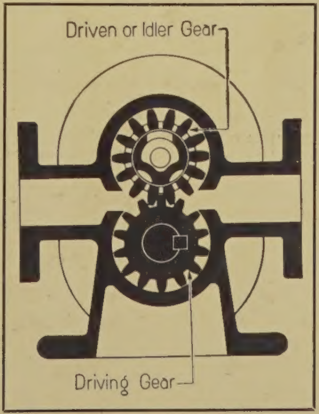

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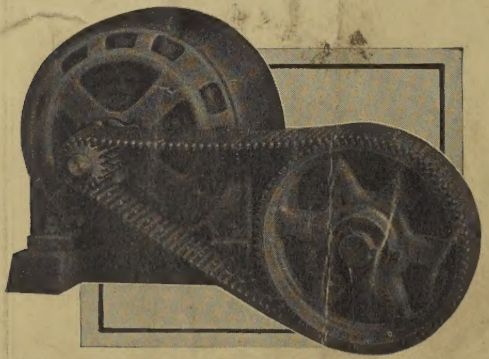

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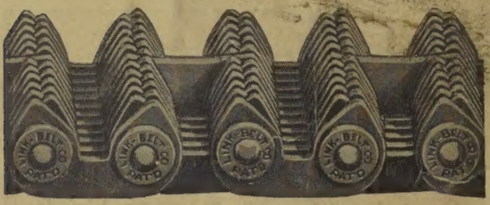
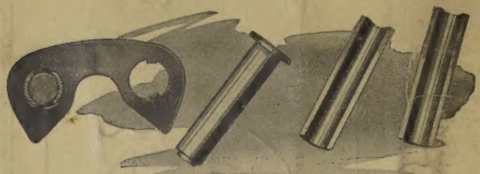


Middle Guide Insures the chain remaining on the wheels



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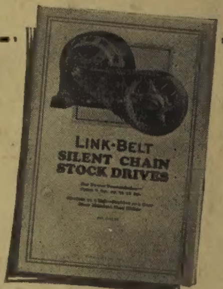

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